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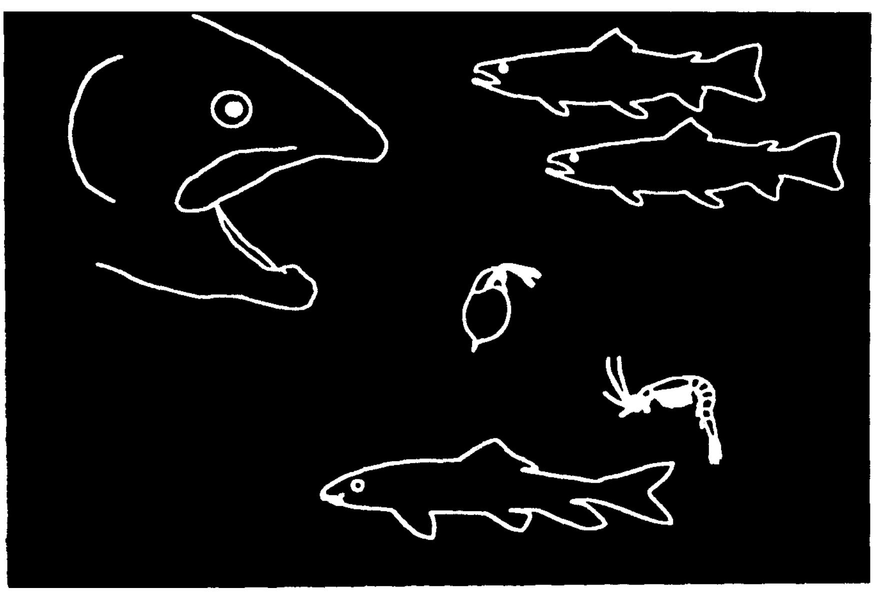
FISHERY RESEARCH

KOKANEE POPULATION DYNAMICS

Job Completion Report
Project F-73-R-13

Job 1. Cost, Benefits and Risks of Salmonid Predators in Kokanee Waters
Job 2. Statewide Kokanee Inventory: Prediction of Yield



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JOB PERFORMANCE REPORT

State of: Idaho

Name: Status and Analysis of Salmonid Fisheries

Project No.: F-73-R-13

Title: Kokanee Population Dynamics

Subproject No.: II

Job 1: Costs, Benefits, and Risks of Salmonid Predators in Kokanee Waters

Study No.: II

Period Covered: March 1, 1990 to March 31, 1991

ABSTRACT

We used available data and age-structured population and bioenergetic models to evaluate the relative costs, benefits, and risks of using salmonid predators with kokanee. About 50% of fall kokanee biomass could be available as production for predators. The actual proportion will vary with growth and mortality in the kokanee population. Existing estimates of kokanee biomass ranged nearly an order of magnitude and were strongly correlated with indexes of lake or reservoir productivity. Kokanee production will range by an order of magnitude or more in Idaho lakes. Estimates of total prey consumption and yield to consumption ratios were similar for lake trout and chinook salmon. The distribution of consumption over the life of a cohort, the consumption of kokanee, and the expected yield at realistic exploitation rates differed substantially between lake trout and chinook. Chinook should produce the best yields in lakes where kokanee are the dominant or only forage. Lake trout should provide the best yields where a diversity of forage is available. Lake trout represent a greater risk of collapsing a kokanee population. Conversion of kokanee production to predator yield is relatively inefficient (about 10%). The channeling of kokanee production through an additional trophic level is high risk in unproductive lakes unless the kokanee fishery is of little value. Stocking rates for lake trout and chinook should be less than 7 fish/hectare. Past stocking rates in Idaho have been much higher and may explain the collapse of some kokanee populations and the failure of some predator introductions. Our results and methods can be used to evaluate predator management alternatives in Idaho kokanee waters.

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PREDTEXT

INTRODUCTION

Kokanee provide an ideal forage for piscivorous salmonids. Kokanee are typically abundant in open water, often in large schools. In a normal kokanee population, the presence of several ages results in a progression in forage size from about 50 mm to 250 mm or larger. Most piscivorous salmonids can use an abundant fish forage throughout their lives. Salmonids such as lake trout, bull trout, rainbow trout, and chinook salmon prey heavily on kokanee. Predator growth rates are often very high, and world record class fish are not uncommon. As a result, kokanee waters have produced some of the most important trophy fisheries in Idaho and the northwest.

There are important trade-offs and risks with the use of any predators. The transfer of energy from one trophic level to the next means that a substantial cost in lost kokanee production must be paid for any new production of predators. The range in productivity of Idaho waters also will have an important influence on potential production and yield. An unproductive lake cannot produce the same yields and, presumably, cannot support the same numbers of predators as a more productive water. Attempting to create a predator fishery in an unproductive lake based on experiences in more productive systems may result in unrealistic expectations or inappropriate risks. Predatory salmonids have been associated with changes in the structure of forage fish communities (Stewart et al. 1983; Aadland 1987) and may result in the collapse of some populations (Stewart et al. 1983; Ney and Orth 1986; Stewart and Ibarra in press; Aadland 1987), including kokanee (Bowles et al. 1991; Beattie et al. 1990).

There may also be important differences among the predators used in kokanee waters. Maximum sizes are similar (>10 kg), but specific growth rates, longevity, prey and habitat selection, and other characteristics may not be. Stewart (1980) showed that prey consumption over life differed dramatically between cohorts of lake trout and chinook salmon. Sustainable yields and harvest rates will also differ substantially between short- and long-lived species (Francis 1986). Lake trout and bull trout may exploit benthic forage as well as kokanee, while chinook or rainbow may be restricted almost entirely to kokanee. It should not be assumed that one predator represents the same trade-offs or risks as another, or that one will do as well as another.

Fisheries management will influence predation. Because trophy fisheries are popular and highly visible, Idaho has tried to establish large salmonids in most kokanee waters. Predators have also been used to control over-abundant kokanee. In some cases, the introductions have produced the desired results. In other cases, predators have performed poorly or have been associated with the collapse of the kokanee population. Predator populations are necessarily low in numbers, and despite the availability of very large fish, catch rates are often relatively poor. Heavy or increasing exploitation may also result in declines in success rates and size of fish. The imposition of special regulations might enhance existing trophy fisheries, as would supplementation with hatchery stocks. Rieman and Beamesderfer (1990) showed that relatively minor changes in annual exploitation (0% to 20%) of a predator population could produce a 50% reduction in prey consumption.

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Management of predator and forage populations has been inconsistent and often with little quantitative or ecological basis (Ney and Orth 1986; Ney 1990). In Idaho, stocking rates for predatory salmonids in kokanee lakes have ranged fully two orders of magnitude (<1 to >600 fish/hectare. Supplementation of predators with hatchery stocks has occurred simultaneously with new restrictions in harvest. Predators have been stocked when kokanee populations were already unstable or depressed and in concert or competition with other attempts to control or harvest kokanee production. The selection of a particular predator species often is based on tradition or local preference rather than an anticipated difference in performance or important characteristics. Over-stocking of predators may explain the collapse of some kokanee populations and the failure of some introductions in Idaho. Lack of concise usable information on kokanee production and predator forage demands means management decisions regarding predator stocking are merely guess work.

The purpose of this project was to describe the relative costs, benefits, the risks of, and recommendations for, the use of predators in Idaho kokanee waters. Our objectives were:

1. to estimate the potential kokanee production available to predators in Idaho waters;

2. to estimate the range of consumption of kokanee expected by different predators with varied growth and life history characteristics;

3. to estimate the yield of predators (benefit) relative to kokanee production consumed (cost) expected for different predators with varied growth and life history characteristics; and

4. to recommend appropriate stocking rates and estimate potential yields for different predators in Idaho kokanee waters.

Our approach was two-fold. First we estimated potential kokanee production based on empirical relations of standing stock and lake productivity. We used age-structured population models to simulate kokanee production relative to standing stock under varied growth and mortality. We assumed that most production lost to mortality in a stable population could be channeled to predators (Eck and Brown 1985; Ney 1990; Coulter 1981) and, thus, estimated the proportion of kokanee biomass potentially available as forage.

Second we estimated consumption of kokanee and yields for predators with a similar age-structured model. We used a production-based approach (Ney 1990; Rieman and Beamesderfer 1990) where simulated production was weighted by expected conversion efficiencies to estimate consumption. The model allowed us to simulate total and specific prey consumption and yield to a fishery under varied conditions of growth, longevity, exploitation, mortality, and prey selection.

By comparing the results of the two models, we were able to approximate both the numbers of predators necessary to consume potential kokanee production (and thus appropriate stocking rates) and the yields that could result. Differences among the variety of simulations illustrate the dynamics of predation, the possible influences of management, and the differences expected among predators.

Lake trout, rainbow trout, bull trout, Atlantic salmon, and chinook salmon have all been introduced in kokanee waters. We did not have time for work with all five species. Our approach relied on estimates of bioenergetic parameters that are very similar or identical for most salmonids. As a result, the major differences in simulations of prey consumption among predator species will result from differences in life history characteristics and prey selection (D. Stewart, State University of New York, personal communication). For that reason, we chose to examine only lake trout and chinook salmon as the two species with the greatest differences in those characteristics. We assumed that results of similar analyses for the other species would be intermediate to those for lake trout and chinook.

METHODS

Potential Kokanee Production

Estimates of standing crop or mean annual production in a prey population represent relative measures of forage available to predators. The estimates are useful to compare forage availability among lakes, but not necessarily the absolute forage production that can be used by predators (Ney 1990). The proportion of forage production that can be channeled to the next trophic level will depend on other sources of mortality and on production necessary for maintenance of the forage population. Some components of mortality are compensatory. Mortality will decline if predation increases. Predation may be the cause of most mortality once fish enter the lake (Leach et al. 1987). Much, if not most, of the production not needed for maintenance may be channeled either to predators or fishermen (Coulter 1981; Eck and Brown 1985).

We assumed all production lost to annual mortality after emergence could be channeled to predators. Predators cannot be so efficient that they take every dying fish, but such an assumption provides an upper limit of available production (Ney 1990).

Production Model

We used an equilibrium yield model (Ricker 1975) to estimate forage production equivalent to estimates of yield to fishing. We replaced fishing mortality with predator mortality and calculated "yield" to predators. We summed results over all cohorts and time periods to estimate a ratio of production (potentially available to predators) to fall kokanee biomass (PP:B). We could then use the PP:B ratio to approximate the production potentially available to predators from empirical or predicted estimates of kokanee biomass in Idaho lakes.

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In the model, we allowed total mortality (summed over all time periods and cohorts from egg to adult) only equal to that necessary to maintain the population in equilibrium. We calculated total mortality at equilibrium to produce replacement for one spawning pair given the fecundity of an average size female. We assumed a sex ratio of 1:1. For example, the fecundity of an average female might be 400 eggs. Total survival necessary for replacement is 2/400 = 0.005 or an instantaneous mortality rate of 5.30. In the model, the total of 5.30 was divided among all periods and cohorts.

To reduce bias in production estimates from interpolation across intervals (Ricker 1975), we used time periods of one-quarter of a year. We assumed growth occurred only during a 6-month period. About one-third of annual growth occurred in the third quarter and two-thirds in the last quarter (Bowler 1980). Mortality to predation took place throughout the year. We summarized biomass at the end of the growing period (fall) equivalent to our time of population sampling (Rieman and Myers 1990a).

We used a series of simulations where growth and the distribution and forms of mortality were varied to explore the possible range of PP:B ratios. We used a base simulation where growth and mortality represented our best guess of a typical population. We then varied individual parameters to describe the uncertainty related to our assumptions.

Mortality-For the base simulation, we assumed survival from potential egg deposition to emergence of 0.40. Survival of 0.40 is representative of values observed in spawning channels (Harvey Andrusak, British Columbia Fish and Wildlife Branch, Victoria, British Columbia) and experiments with moderate to low sediment in the incubation environment (Irving and Bjornn 1984) and, presumably, very good conditions in the wild. Production during incubation was not available to predators. In alternative simulations, we assumed incubation survivals of 0.10 and 0.80 (Appendix A). We considered the range representative of degraded conditions in the wild and a hatchery-supported population, respectively.

We assumed mortality from emergence to fall age 0 of 90%. The mortality during this period was selected to provide a survival of 0.04 from potential egg deposition to fall age 0 in our base simulation. Four percent represents the upper range of estimates for our wild populations.

For the base simulation, remaining mortality was apportioned equally among remaining time periods in the model. We have some evidence that predators select kokanee 150 mm to 200 mm long more heavily than larger or smaller fish. As an alternative simulation, we focused most mortality on age classes representing that size range. Fishing is also important in many populations. Another alternative allocated mortality to fishing equivalent to an annual exploitation rate of 0.30 on mature fish. Mortality to fishing represented production not available to predators. The mortality schedules used in our range of simulations is summarized in Appendix A.

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Growth and Age at Maturity-For the base simulation, we used annual growth equal to that in lakes of intermediate productivity and kokanee density (Rieman and Myers 1990a). As alternatives, we used a higher growth rate (representative of low densities in the same lake or moderate densities in an unproductive lake) and a lower growth rate (representative of very high densities or an unproductive lake) as outlined in Appendix B.

We assumed that kokanee matured at age 3+ in simulations using base and high growth. Age at maturity varies both among and within populations. Age 3+ is common among most populations and the dominant age of maturity in populations with good growth. As growth slows, age at maturity may increase. Older fish are common in unproductive lakes. In simulations with the low growth rate, we added a final year to the simulation with fish maturing at age 4+. Age at maturity of 4+ resulted in an adult size of about 210 mm. This is near the minimum size observed in our populations (Rieman and Myers 1990a).

We predicted fecundity from a relationship with total length of females from several Idaho populations.

Empirical and Predicted Biomass

We used estimates of kokanee biomass in ten Idaho lakes and one Oregon lake as the basis for production estimates. Biomass estimates were made with a mid-water trawl as outlined by Rieman and Myers (1990a). We related biomass to indices of lake productivity with correlation and regression analysis. We used original estimates and log transformations of both variables. We report only the "best fit" results. The indices of lake productivity are the same as those summarized in Rieman and Myers (1990a) and Myers and Rieman (1990), with the exception of data for Dworshak Reservoir which was updated with sampling in 1990.

Some of the kokanee populations represented in the data base were obviously depressed. To predict potential kokanee production, we analyzed the data with all observations and without the depressed populations. We considered a population depressed if recent estimates or information on spawning escapement showed that the population was at 25% or less of historic abundance.

Predator Consumption and Yield

Predator Model

We used a production-based approach to simulate consumption (Ney 1990). We used an age-structured equilibrium yield model (Ricker 1975) to predict consumption and yield (to fishing) for chinook salmon and lake trout. We made predictions under varied conditions of growth and exploitation. We estimated total prey consumption as the product of production (total tissue elaboration regardless of fate) and gross conversion efficiency for each age class and interval in the model (see, for example, Rieman and Beamesderfer 1990). Yield was estimated directly as outlined by Ricker (1975). Parameters for the model were estimated from observations in North Idaho lakes or from the literature. We assumed that natural mortality acted concurrently with any exploitation.

We used time intervals in the model relative to the life span and growth of the species. To reduce bias in production estimates over intervals of fast growth and high mortality, we used shorter time intervals for chinook than for lake trout. For chinook, we assumed that all fish matured and died after four years. We used one-quarter-year intervals in the model for a total of 12 intervals. For lake trout, we assumed that no fish lived past age 15 and used one-year intervals in the model for a total of 15. With the intervals that we selected, estimates of production and consumption were within 10% of our estimates from the bioenergetics model of Hewitt and Johnson (1987) where daily time steps were used. Lake trout may live longer than 15 years (Scott and Crossman 1973). Fish at that age, however, contributed little to total consumption, yield, or stock biomass in any simulations except for those with no exploitation. Consideration of longer living fish would have little or no influence on the results of our simulations.

Recruitment in the model was held constant, reflecting either natural populations in equilibrium or hatchery-supported populations with stable stocking. Results represent consumption and yield for an average cohort over its life or one year in a population that is fully established and stable (Ricker 1975).

We summed yield and consumption for each age class over all years. We ran all simulations with an initial population of 1,000 fish in the first age class and time interval. Results were expressed as the total consumption per recruit and as the ratio of yield to consumption. In the case where we assumed a diet of several prey items, consumption estimates for each age class were modified to reflect consumption of kokanee only.

We ran base simulations with our "best estimates" for model parameters. We ran a series of alternative simulations to explore the relative influence of changes or uncertainty in key parameters.

Age at Maturity-Chinook stocked in freshwater lakes typically mature in two to five years (Horner and Rieman 1985; Aadland 1987; Stewart et al. 1981). Most fish used in Coeur d'Alene Lake have matured at age 3+, which we assumed in the base simulations. We did not explore alternatives in age at maturity. Fish maturing later will consume more prey and will have lower production:biomass ratios and conversion efficiencies (Kitchell and Hewett 1987). Our yield estimates will be optimistic, and consumption estimates will be conservative if fish mature later than age 3+.

Lake trout begin to mature at about 450 mm in length, with 905 maturity for fish between 500 and 600 mm in many populations (Hanson and Wickwire 1967;

Healey 1978). We assumed that lake trout matured fully at 600 mm or about 2,000 grams. We assumed spawning every year, a sex ratio of 1:1, and an average loss of body weight of 6.8% for the sexes combined (Stewart et al. 1983). Consumption was adjusted in the model to reflect the production lost to spawning. We did not make any alternative assumptions about age at maturity_ for lake trout. Although age at maturity may vary, the influence on total consumption will be relatively small (± about 7% for each year of change) unless deviations are very large relative to our base simulation.

Growth-For each species, we ran simulations with two growth rates to represent weight at age under conditions of high and low forage availability. Ney (1990) suggested that consumption at the maximum possible growth for a predator represents potential forage demand. Maximum possible growth can be predicted through bioenergetics models by assuming a relative forage availability of 100% (Hewitt and Johnson 1987). Rather than maximum possible growth rates, we used upper growth rates actually observed with moderate or strong limnetic forage populations. We assumed these growth rates reflect the potential with kokanee available as forage. We used the upper growth rates for the base simulations. As a lower bound, we used growth that approximated observations with depressed kokanee populations.

For lake trout, we selected growth that bounded the growth observed in Lake Michigan (Stewart et al. 1983) and growth predicted for lake trout in Priest Lake under conditions of high and low kokanee numbers (Mauser et al. 1988) (Figure 1). We assumed that lake trout enter the lake at 8 g.

For chinook salmon, we used growth bounding that observed in several fresh water systems, including Coeur d'Alene Lake with a strong kokanee population and Anderson Ranch Reservoir with a weak kokanee population (Figure 2). We assumed that all chinook entered the lake at 40 g in June (similar to stocking goals for Coeur d'Alene Lake).

Mortality-Mortality in the model included fishing and natural causes. Healey (1978) suggested maximum sustainable exploitation (proportion of initial stock harvested annually) of lake trout is from 0.30 to 0.40. Exploitation was estimated at about 0.30 in Lake Michigan (Rybicki and Keller 1978) and 0.23 in Priest Lake (Mauser et al. 1988). In our model we estimated that maximum yield for lake trout with the upper range of growth was at exploitation of about 0.23. In our simulations, we used a range of fishing mortality equivalent to annual exploitation rates of 0.00 to 0.50. The base simulation was with exploitation of 0.23. We assumed lake trout became fully vulnerable to exploitation at about 380 mm (Mauser 1986).

We found no documentation of exploitation rates for chinook in freshwater. In the simulations, we used a range of annual exploitation from 0.00 to 0.80. Maximum yield was at exploitation of about 0.65. We used 0.40 as the base rate. We assumed that chinook became fully vulnerable to exploitation in the second year regardless of size (unpublished data, Idaho Department of Fish and Game, Region 1).

PREDTEXT

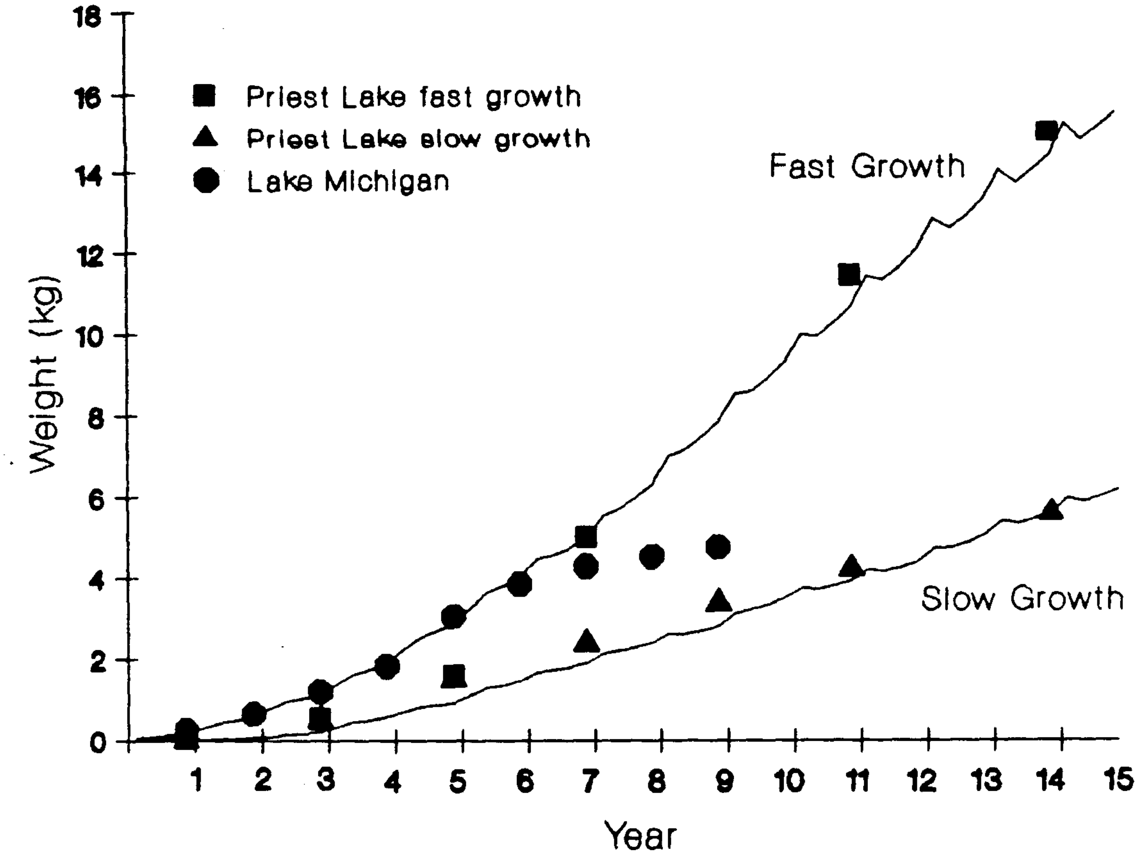

Figure 1. Weight at age used in simulations of prey consumption for lake trout. Weights were selected to bound observations of high and low growth in other systems. Observations are from Stewart et al. (1983) for Lake Michigan, and Mauser et al. (1986) for Priest Lake.

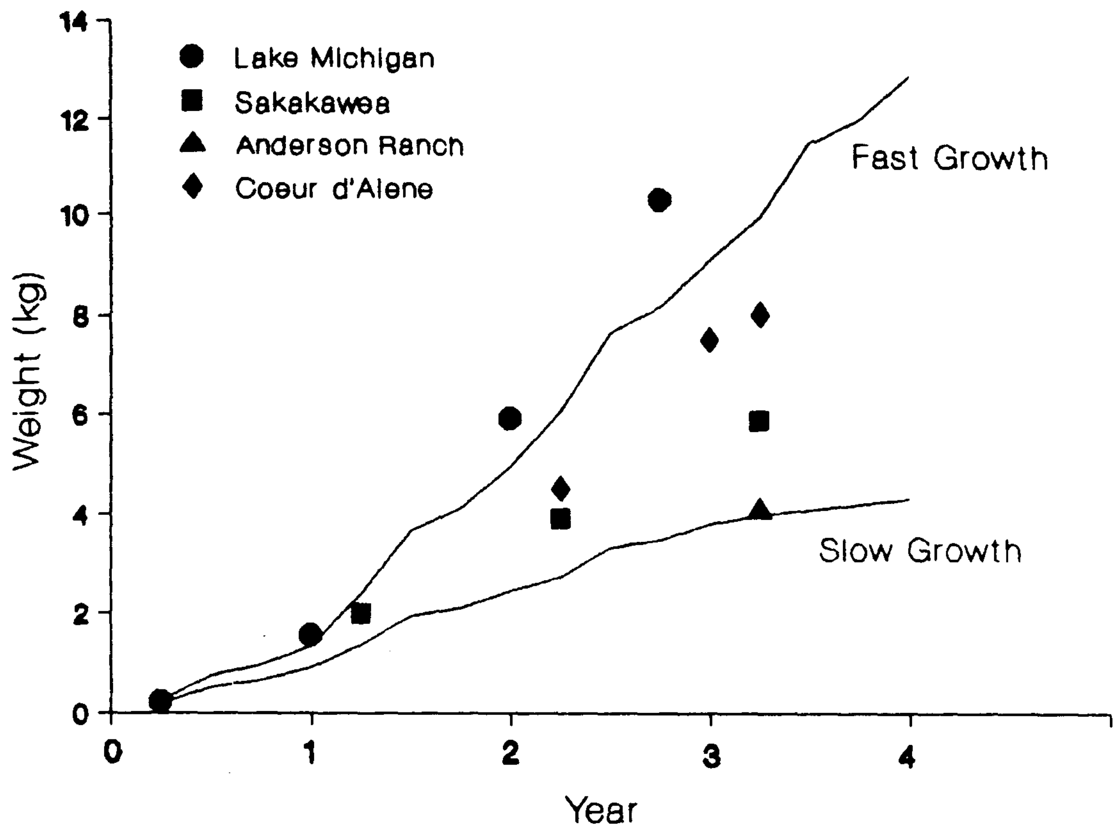

Figure 2. Weight at age use in simulations of prey consumption for chinook salmon. Weights were selected to bound observations of high and low growth in other systems. Observations are from Stewart et al. (1981) for Lake Michigan, Aadland (1987) for Lake Sakakawea, Partridge (1988) for Anderson Ranch Reservoir, and Horner and Rieman (1985) and Horner et al. (1989) for Coeur d'Alene Lake.

Conditional natural mortality estimates for lake trout have been estimated from 0.20 to 0.30 (Mauser 1986; Healey 1978; Rybicki and Keller 1978). We assumed natural mortality equivalent to 0.26 for all age classes in our simulations.

Stewart (1980) estimated total annual mortality of chinook not recruited to the fishery in Lake Michigan at about 0.52. We found no other estimates and assumed conditional natural mortality of 0.50 for all age classes in our simulations.

Initial survival for hatchery-stocked fish may be highly variable. As an alternative to our base simulations, we assumed survival in the first age class (but not following ages) half that in the base simulations. We did not use any other alternatives regarding natural mortality. Although our assumptions of natural mortality may be wrong, total mortality in all of the simulations ranged from about 26% to 66% annually for lake trout and 50% to 90% for chinook. The range of total mortality should account for most of the variation possible in any population.

Prey Selection-Lake trout forage extensively on kokanee. Even when kokanee are abundant, however, other prey can be important, particularly for lake trout less than 500 mm (Rieman and Lukens 1979; Luecke and Yule 1990; Matuszek et al. 1990). Rieman and Lukens (1979) and Mauser (1986) found that mysids dominated the diet of lake trout under about 500 mm in length. Fish, mostly kokanee, were important beyond that size. Bjornn (1957) found that lake trout longer than 190 mm used kokanee and that kokanee were the dominant prey for the largest size classes. Small lake trout (<200 mm) could prey on juvenile kokanee, but that has not been documented. To represent uncertainty in prey selection for lake trout, we made two assumptions. As an upper bound we assumed that all lake trout used only kokanee. As a more realistic alternative, we assumed that lake trout smaller than 200 g did not use kokanee. We assumed that kokanee made up 20% of the diet for fish between 200 and 1,800 grams and 80% of the diet for lake trout over 1,800 grams.

Chinook may use a variety of prey including invertebrates (Aadland 1987; Stewart 1980). However, as chinook grow, they quickly switch to limnetic fishes (Stewart and Ibarra in press). Kokanee were the only prey observed in any chinook stomach samples from Coeur d'Alene Lake. Chinook of 40 g are capable of consuming juvenile kokanee (LaBolle 1988). Kokanee are the only, or dominant, limnetic forage in most Idaho lakes. We, therefore, assumed prey composition for chinook in our simulations to be 100% kokanee.

Conversion Efficiency-We defined gross conversion efficiency as the ratio of growth divided by total food consumption. Both estimates are in wet weight per individual. To estimate food consumption, we weighted production in each age class and time period by the inverse of gross conversion efficiency (Rieman and Beamesderfer 1990; Ney 1990).

PREDTEXT

We estimated conversion efficiencies for chinook salmon and lake trout with the Wisconsin bioenergetics model (Hewitt and Johnson 1987). Our parameter estimates for the bioenergetics model were identical to those of Stewart et al. (1981), Stewart et al. (1983), Kitchell and Hewett (1987), and Stewart and Ibarra (in press). The growth, mortality, maturity, and longevity schedules we used are explained above.

We assumed predator temperature preferences identical to Stewart and Ibarra (1991). We predicted the temperature experience for each predator from temperature data in Coeur d'Alene Lake, Idaho (Appendix C). From Stewart and Ibarra (in press, cited from Brett et al. 1969), we estimated energy density for O. nerka (estimated for the sizes used as prey in our lakes) to range from 1,379 cal/g to 1,449 cal/g. We assumed a constant value of 1,400 cal/g for all prey.

We summarized the output from the bioenergetics models to estimate conversion efficiency over 91-day periods for chinook and one-year periods for lake trout. The estimated conversion efficiency for each age class and time period corresponded directly to those used in our yield model.

RESULTS

Kokanee Production

Estimates of production that could be available to predation (PP:B) ranged from 40% to almost 70% of total production (Table 1). Our base simulation of production to mortality was 47% of total biomass (Table 1). Changes in growth had the largest influence on PP:B. The alternative simulations in growth and incubation survival both produced about a two-fold range in the proportion of biomass that could be channeled to predation.

Estimated biomass in 11 kokanee lakes ranged from less than 1 to over 90 kg/hectare (Figure 3). Log_e biomass was correlated with chlorophyll 'a' and Secchi transparency (Table 2, Figure 3). Chlorophyll concentrations explained about 66% of the variation in biomass estimates when depressed populations were removed from the sample. Predictions of potential kokanee biomass based on regression against chlorophyll 'a' ranged 20- to 30-fold over the range of chlorophyll in our waters (Table 3).

Predator Consumption and Yield

Estimated conversion efficiencies for lake trout and chinook declined with age from about 0.30 in youngest fish to 0.08 or less in the oldest age classes (Table 4). Conversion efficiency was similar at age for fast- and slow-growing lake trout, but was lower with slow growth in relation to size of fish. For chinook conversion efficiencies relative to age and size of fish differed more markedly between fast and slow growth than for lake trout. Our estimated

Table 1. Simulated ratios of kokanee production lost to mortality to total production and fall biomass under varied survival, exploitation, and growth. The ratio of total production to fall is also shown.

	Mortality: Production	Mortality: Biomass	PP:B
Estimate	0.56	0.47	0.84
Low incubation survival (10%)	0.40	0.30	0.75
High incubation survival (80%)	0.65	0.58	0.89
Exploitation in fishery (30%)	0.41	0.34	0.84
Focused mortality	0.42	0.32	0.76
High growth[a]	0.69	0.66	0.96
Low growth[a]	0.56	0.29	0.51

[a]Fecundity also was adjusted to be consistant with size at maturity.

PREDTBLS

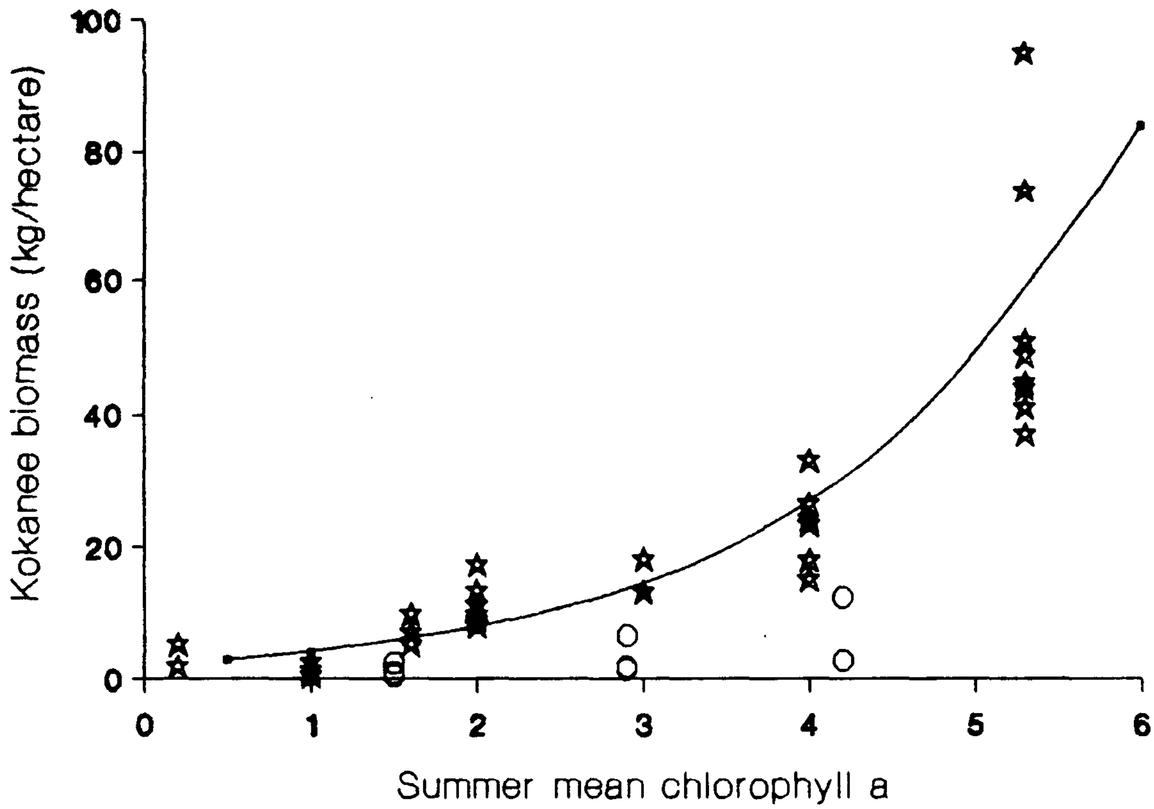

Figure 3. Relation of estimated kokanee biomass (wet weight) and chlorophyll a in 10 Idaho lakes and reservoirs. The regression line was fit to the data excluding depressed populations.

Table 2. Pearson correlation coefficients between different expressions of kokanee biomass and chlorophyll 'a' or Secchi transparency. Sample sizes are shown in parentheses.

	(n)	Chlorophyll	Secchi
Kg/hectare	(46)	0.78	0.59
Log_e kg/hectare	(46)	0.74	0.54
Mean kg/hectare	(46)	0.75	0.47
Log_e mean kg/hectare	(11)	0.72	0.54
Select log_e kg/hectare[a]	(25)	0.82	0.65
Select kg/hectare[a]	(35)	0.88	0.58
Maximum kg/hectare	(11)	0.47	0.62
Log_e maximum kg/hectare	(11)	0.76	0.74

[a]Observations from depressed populations were eliminated.

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Table 3. Chlorophyll 'a', Secchi transparency, and observed and predicted biomass of kokanee for eleven lakes and reservoirs.

Lake	Chlorophyll 'a'	Secchi transparency (m)	Observed Mean biomass kg/hectare (n)	Predicted[a] biomass kg/hectare
Pend Oreille	2.0	6.5	10.2 (9)	7.4
Priest	1.5	8.0	1.3 (3)	5.5
Coeur d'Alene	4.0	5.0	23.3 (6)	24.9
Payette	1.0	9.0	2.7 (4)	4.0
Upper Priest	2.9	6.0	1.7 (2)	12.8
Spirit	5.3	3.9	54.5 (8)	54.9
Anderson Ranch	4.2[b]	3.4	7.6 (2)	28.1
Odell	3.0	7.0	16.3 (3)	13.6
Alturas	<1[b]	13.0	5.2 (1	<4
Redfish	<1[b]	14.0	1.8 (1	<4
Dworshak	1.6	4.5	7.3 (3)	5.8

[a]Predicted from the observations of biomass and chlorophyll where obviously depressed populations were eliminated from the model
[b]Predicted from regression on Secchi transparency as described by Rieman and Myers 1990.

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Table 4. Conversion efficiency for lake trout and chinook salmon estimated using the Wisconsin Bioenergetics Model[a]. Lake trout estimates are on an annual basis; chinook are on a quarterly basis. Estimates are for two growth rates bounding the range expected with kokanee as forage.

		Chinook				Lake trout			
		Fast growth		Slow growth		Fast growth		Slow growth	
Year	Ending day	Weight (g)	Conversion	Weight (g)	Conversion	Weight (g)	Conversion	Weight (g)	Conversion
1	91	256	0.34	189	0.32				
1	182	754	0.36	520	0.36				
1	273	962	.25	654	0.24				
1	365	1,347	.26	912	0.27	176	0.30		0.30
2	91	2,396	.18	1,365	0.14				
2	182	3,675	.185	1,948	0.19				
2	273	4,114	.133	2,121	0.13				
2	365	4,953	.165	2,454	0.16	581	0.23	52	0.21
3	91	6,052	.09	2,720	0.06				
3	182	7,644	.13	3,313	0.13				
3	273	8,158	.09	3,475	0.08				
3	365	9,055	.11	3,806	0.11	1,161	0.17	205	0.23
4	91	9,928	.05	3,980	0.03				
4	365					1,899	0.14	584	0.21
5	365					2,863	0.14	934	0.14
6	365					4,029	0.12	1,458	0.13
7	365					4,960	0.11	1,901	0.12
8	365					6,304	0.11	2,385	0.12
9	365					7,823	0.10	2,785	0.10
10	365					9,270	0.09	3,492	0.12
11	365					10,634	0.08	3,904	0.09
12	365					12,041	0.08	4,37	0.09
13	365					13,279	0.07	5,020	0.09
14	365					14,391	0.07	5,611	0.09
15	365					15,528	0.06	6,181	0.08

[d]Hewitt and Johnson 1987.

conversion efficiencies for both lake trout and chinook were similar to those predicted for the same species in Lake Michigan (Stewart et al. 1983; Stewart and Ibarra in press).

Simulated total food consumption for lake trout ranged from about 1,300 to 20,000 g/recruit (Appendix D). Estimated consumption for the base simulation was about 8,000 g and was less than half of that under no exploitation (Table 5). Slow growth or low initial survival reduced the base estimate by about half again. The assumption that kokanee represent only part of the diet had a large influence on estimated consumption (reduced by 50% to 75% relative to the base simulation) that was most pronounced under slow growth (Table 5).

The estimated consumption for chinook ranged from 5,200 to 20,500 g/recruit and was similar to that for lake trout (Appendix D). Assumptions regarding exploitation, growth, and survival also had similar though less pronounced effects on the estimates of total consumption.

Estimated consumption over the life of a cohort peaked in the third to sixth year for lake trout (Figure 4). Consumption persisted at a relatively high level (10% or more of the peak) at least into the ninth year. Exploitation shifted the peak in consumption to earlier years, while the assumption that kokanee represent only part of the diet shifted the peak later (Figure 5).

Estimated consumption over life for chinook peaked at year two or three. Peak consumption within an age class was several times that observed in lake trout, but obviously stopped after year four. Exploitation also shifted peak consumption to earlier ages in chinook (Figure 5).

The ratios of yield to total consumption (Y:C) for lake trout and chinook salmon were remarkably similar over the range of exploitation common to both species (Figure 5). The Y:C increased in linear fashion with increasing exploitation. Our alternative assumptions regarding growth had little effect on the results. Because lake trout and chinook probably cannot support the same level of exploitation, sustainable Y:C will differ. From our base simulations we estimate that chinook will be almost two times (Y:C = 0.10 vs 0.06) as efficient as lake trout in converting total food consumption to yield (Appendix E). If we consider the maximum yield (not necessarily sustainable) in our simulations, the discrepancy might be higher (Y:C = 0.14 vs 0.06) (Appendix D).

When we considered only kokanee in lake trout diets, the Y:C improved substantially (Figure 5). Simulations for slow-growing lake trout produced the highest ratios. If lake trout are more diverse in their food habits than chinook, the Y:C should be similar to or better than chinook. Under our assumptions of prey selection, the base estimates of Y:C for lake trout ranged from about 0.13 to 0.21 relative to 0.10 for chinook (Figure 5, Appendix D).

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Table 5. Selected estimates of consumption (g) per average individual predator stocked over life.

	Chinook total	Lake trout total	Lake trout kokanee only
Estimate[a]	10,400	7,600	3,700
Maximum yield[b]	7,000	7,600	3,700
Unexploited	20,500	19,600	12,700
Slow growth	5,400	4,100	1,300
Low initial survival	5,200	3,800	1,850

[a]Assumes highest growth; conditional natural mortality of 0.50 for chinook and 0.26 for lake trout; exploitation at 0.42 for chinook and 0.23 for lake trout.
[b]Maximum yield per recruit occurred with E = 0.65 for chinook and E = 0.23 for lake trout.
Assumes survival in first year is half of that experienced in following years.

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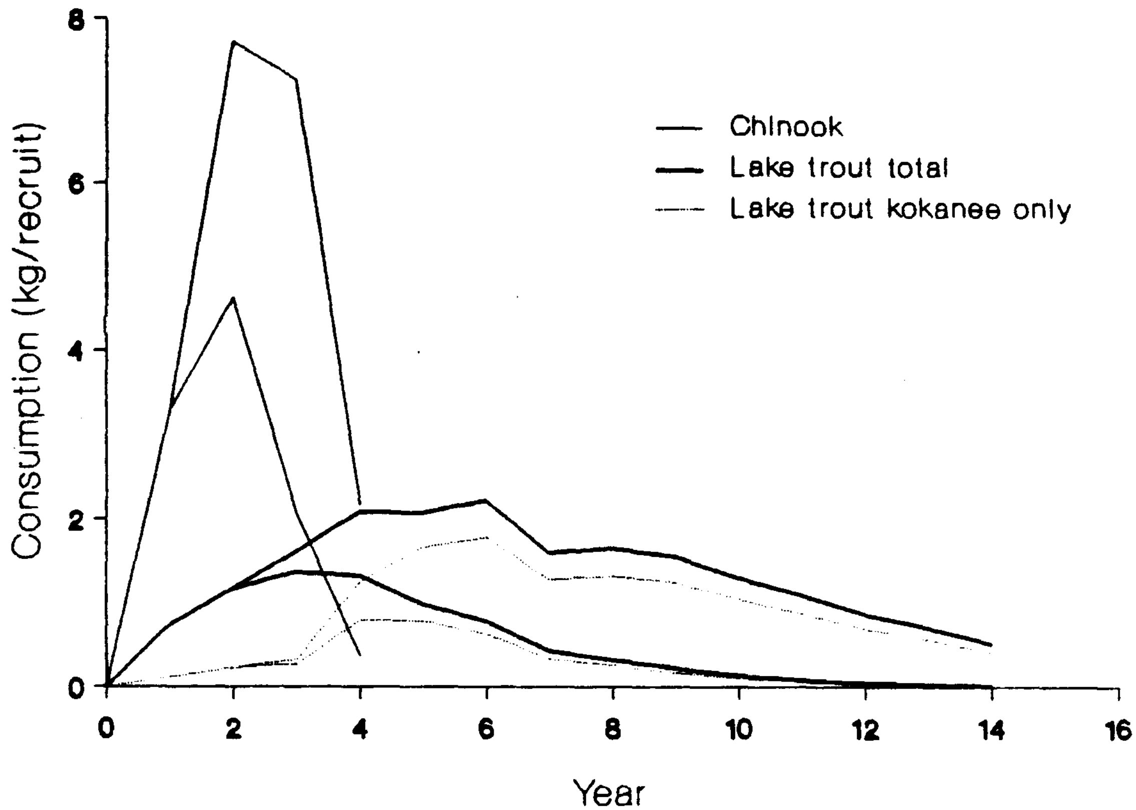

Figure 4. Examples of estimated prey consumption per recruit by year after lake entry for lake trout and chinook salmon. Examples for chinook show exploited and unexploited populations. Examples for lake trout show exploited and unexploited populations with consumption of total food and of kokanee only.

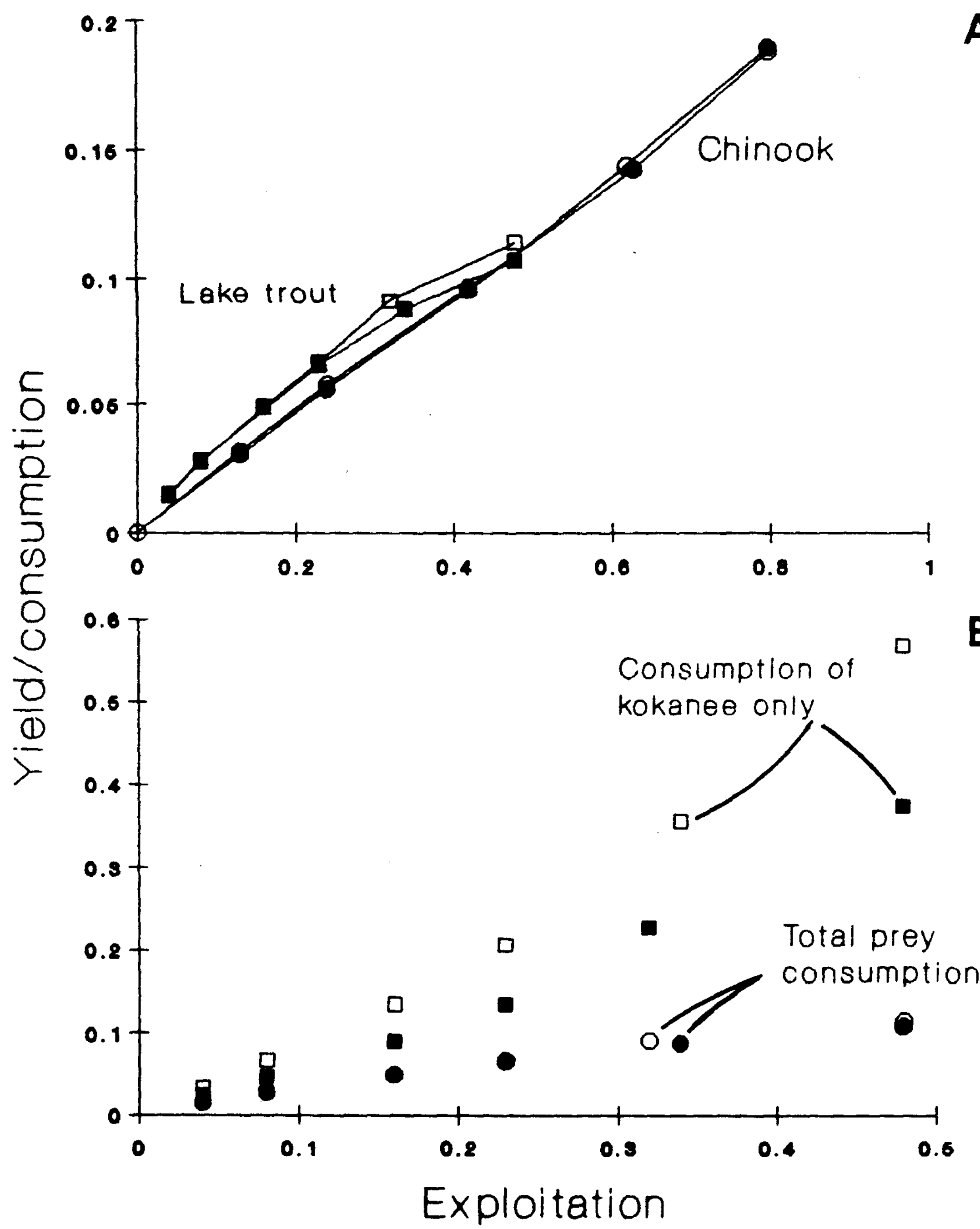

Figure 5. Simulated ratios of yield to consumption for lake trout and chinook salmon under varied growth and exploitation. Open points represent high growth and closed points represent low growth. Panel A shows ratios for total prey consumption by both predators. Panel B shows ratios for consumption of total prey and of kokanee only for lake trout.

Potential Predator Yield and Stocking Rates

In a stable population, potential predator yield should be equal to the product of the Y:C and forage production available to predation. Given our previously derived estimates, potential yields for chinook and lake trout should range from 2% to 10% of kokanee biomass (Table 6). The base simulation results produce overall estimates of potential predator yield that range an order of magnitude for our lakes (Table 7) from 2.2 to .22 kg/hectare/year for chinook.

Stocking rates necessary to consume all available kokanee production can be estimated by dividing the predicted biomass available to predators by the estimate of consumption for an average predator over its life. Stocking rates projected for Idaho lakes range an order of magnitude for both chinook and lake trout, but all estimates are less than 7 fish/hectare (Table 7).

DISCUSSION

Potential Kokanee Production

Not all the annual production can be channeled to yield or, in our case, to predators (Ney 1990). Roughly 50% of annual production can be available to predation on a sustained basis (40% to 70%). These estimates are similar to the 0.3 to 0.5 proportion of production assumed available as yield in some exploited fishes (Coulter 1981).

Estimates show that production available to predators will vary with the characteristics of **a** kokanee population and perhaps with management. Growth and initial survival produced the largest (roughly two-fold) variations in the available production. Kokanee growth is strongly related to productivity of the lake (Rieman and Myers 1990a). Thus, more productive lakes should be able to sustain a higher rate of predation than unproductive lakes. Hatchery supplementation of some kokanee populations could also increase the production available. Exploitation in a fishery, or egg collection for the supplementation of other populations, could reduce production available to predation. Hatchery supplementation may pose a risk if production is not stable. If predator stocking were geared to hatchery-supplemented production of kokanee and the hatchery stock failed, the remaining wild stock could be seriously depressed.

A conservative estimate of available production is recommended for predator management. Predator-prey interactions can be unstable (Murdoch and Bence 1987) and unpredictable. Survival of kokanee will vary with environmental events (Rieman and Bowler 1980; Decker-Hess et al. 1985; Fraley et al. 1986; Fraley and Decker-Hess 1987; Bowles et al. 1989; Beattie et al. 1990) and can not be estimated with any precision. Exploitation may vary indirectly with kokanee population size (Rieman and Myers 1990b) and with vagaries of angler distribution. Production available to predation, therefore, must be variable both within and among kokanee populations. Our base estimate of about 50% of

Table 6. Examples of potential yields[a] for chinook salmon and lake trout as a proportion of fall kokanee biomass. Estimates for chinook are for total prey consumption. Estimates for lake trout are for total prey and for kokanee only.

Predator	Base[b] Estimate	Alternative Estimates: Slow predator growth	Slow kokanee[c] growth	High Kokanee[c] growth
Chinook (total)	0.044	0.05	0.03	0.07
Lake trout (total)	0.028	0.03	0.02	0.04
Lake trout (kokanee selection)	0.063	0.10	0.04	0.08

[a]Estimates are based on the ratios of predator yield to consumption (Figure 5) and of available kokanee production to fall biomass (Table 1).
[b]Based on high predator growth and optimum exploitation.
[c]Alternative estimates selected to represent the full range of available production to biomass ratios.

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Table 7. Estimates of appropriate stocking rates and potential yields for chinook salmon and lake trout in select Idaho kokanee lakes of varied productivity and kokanee biomass.

Lake	Summer mean chlorophyll 'a'	Predicted kokanee biomass	Stocking Rate (fish/hectare)		Yield (kq/hectare/year)	
			lake trout	chinook	lake trout	chinook
Spirit	5.3	50	6.7	2.5	3.20	2.20
Coeur d'Alene	4.0	20	2.7	1.0	1.26	0.88
Pend Oreille	1.0	10	1.4	0.50	.06	0.44
Priest	1.5	5	0.7	0.25	0.32	0.22

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biomass should be considered only as a starting point. If a population is particularly unstable, or if a fishery or other source of mortality is important, the estimate should be reduced accordingly. We recommend 50% as an upper bound of the biomass available to predation.

Our relation of biomass and lake productivity indicates that kokanee production or potential production should vary substantially among Idaho lakes. Predicted kokanee biomass for the lakes in our sample ranged an order of magnitude, while the actual estimates ranged even more (Table 3). It should be understood that Idaho lakes will not all produce similar forage or fisheries. Productivity of the lake environment will have an important influence on kokanee and predator production and yield. Like kokanee biomass, production and yield will also vary by an order of magnitude or more across Idaho lakes.

Kokanee cannot incorporate all secondary production. Kokanee do not effectively exploit secondary production from benthic sources (Hall and Hyatt 1974) because they feed almost exclusively on macrozooplankton in the pelagic area (Rieman and Bowler 1980). Eggers et al. (1978) found that the benthic food chain was the *dominant* energy pathway in Lake Washington. Most production was not channeled through limnetic fishes. Hall and Hyatt (1974) also found that estimates of kokanee biomass and trout biomass in Marion Lake were lower than the expected total fish biomass. Kokanee, therefore, represent only a part of the possible forage production in any lake or reservoir. Predators (lake trout and bull trout) that use a more diverse forage community may support greater yields than those (chinook and rainbow) that rely solely on kokanee.

Predator Consumption and Yield

We found striking similarities in estimates of total consumption (Table 5) and the Y:C related to exploitation (Figure 5) for the two predators we considered. The bioenergetic parameters are assumed to be similar for all salmonids. Any differences in consumption estimates must be driven primarily by differences in growth, prey selection, longevity and mortality, and temperature. Fish size and temperature should explain the largest differences in estimates of total consumption (Carline 1987). In our models, lake trout and chinook reached similar maximum sizes, though specific growth rates were much different. Temperatures were also similar. In our simulation, absolute differences in growth rates between the species were compensated by opposing differences in natural mortality and longevity. Our results show that expected differences in total forage demand among salmonid predators are not large. The expected benefits (fishery yields) relative to total forage consumed are also similar as long as exploitation rates are low.

We did see important differences between predators. Estimates of kokanee consumption, the distribution of consumption over the life of a cohort, and the ratio of yield to consumption at realistic exploitation levels all differed substantially between the two species. These differences should be important to predator management.

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Consumption of Kokanee-Our assumptions considering only kokanee as prey reduced consumption estimates for lake trout to roughly one-half to one-third of those for chinook. The shift was clear even though we assumed that kokanee represented the dominant forage (80%) of larger lake trout. The disproportionate shift was the result of a major portion of production and consumption in the younger lake trout that presumably would not use kokanee.

We believe that diets of lake trout in most kokanee lakes will be more diverse than those of chinook salmon. Lake trout consistently use benthic and littoral forage items as well as limnetic fishes (Bjornn 1957; Rieman and Lukens 1979; Matuszek et al. 1990). Although chinook may use a variety of prey (Stewart and Ibarra in press), they appear to use limnetic fishes almost exclusively when available. Chinook in Idaho are stocked at a size capable of preying on juvenile kokanee (LaBolle 1988). In many of our lakes, kokanee are the only limnetic fish. Benthic invertebrates (e.g., mysids and amphipods) and benthic and epibenthic fishes (e.g., yellow perch, sculpins, whitefishes, and various cyprinids) are also common. As a result, we believe lake trout have a larger forage base available than chinook in most lakes.

Differences in consumption estimates produce corresponding differences in suitable stocking rates for the two species. From our base simulations, we estimate that chinook should be stocked at 0.25 to 2.5 fish/hectare. Lake trout could be stocked at two to three times that level (0.7 to 6.7 fish/hectare) (Table 7). Those differences should apply only if the assumptions we used to generate the estimates are consistent for the system in question.

Distribution of Consumption Through Time-The distribution of prey consumption over the life of a cohort was very different for the two predators. The general response has been termed predator inertia (Stewart 1980; Stewart et al. 1981). Lake trout represent a greater inertia than chinook. As a result, the ability to predict forage availability, and conversely to predict the effect of predation on the forage population, will be much different for the two predators (Stewart 1980). Consumption in lake trout should peak four or more years after stocking and continue for much longer (ten or more years). Forage demand by lake trout will persist well beyond our ability to predict kokanee production. If the kokanee population is unstable, optimistic stocking in one year will result in a disparity in forage availability and demand in the future (Ney and Orth 1986). Collapse of the forage population is possible. Chinook will consume far more prey in a short period (two to four years). Chinook, however, will disappear from the system more quickly than lake trout. The inertia in chinook predation corresponds more closely with our ability to estimate kokanee abundance and production. If over-stocking occurs, recovery will be possible earlier with chinook than with lake trout.

Yield:Consumption-Our estimated ratios of yield to prey consumption for lake trout and chinook followed similar increasing patterns with increasing exploitation. The increase in relative efficiency results as fishing takes a larger portion of available predator production and shifts the predator

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population structure more heavily toward young fish. Production (and thus consumption) to biomass ratios are typically higher for young salmonids (Chapman 1978; Waters et al. 1990; Stewart and Ibarra in press). Conversion efficiency is higher in smaller and younger fish as well (Stewart et al. 1983; Table 4). For management, that means that highest benefit (predator yield) to cost (lost kokanee production) will be at the highest exploitation that can be sustained with the predator in question.

Lake trout and chinook cannot be exploited at the same rates to produce maximum yields. Long-lived fishes cannot support the same level of exploitation as short-lived species (Ricker 1975; Francis 1986). The maximum equilibrium yield per recruit in our simulations was at exploitation of about 23% for lake trout but nearer 70% for chinook. When we considered realistic exploitation rates for the two species, chinook were nearly twice as efficient in relation to total food consumption. When we considered only kokanee as prey, however, the diversity in lake trout food habits produced an equivalent or greater benefit in yield per weight of kokanee consumed. Although chinook represent a more efficient transfer of total food to yield, lake trout should provide better yields in systems with a diverse forage base.

Stocking Rates

Appropriate stocking rates for both predators were estimated at less than 7 fish/hectare. The estimates vary with our assumptions, but the range is consistent with experience in successful programs. Stocking rates for chinook have ranged from less than 1 to nearly 5 fish/hectare in Coeur d'Alene Lake (Idaho Department of Fish and Game, unpublished data). Stocking necessary to use surplus kokanee production in Coeur d'Alene Lake appears to be on the order of 2 to 3 fish/hectare (Maiolie, Idaho Department of Fish and Game, personal communication). Recent numbers of all predators stocked in Lake Michigan (Kitchell and Hewett 1987) are equivalent to about 1.8 fish/hectare and may be too high. Predators apparently have depressed, and may collapse, the Lake Michigan forage base (Stewart and Ibarra in press; Stewart et al. 1981; Stewart et al. 1983). Chinook have been stocked at less than 1 to about 7 fish/hectare in Lake Sakakawea (Aadland 1987). Some forage species have been eliminated (Aadland 1987). Stocking in Lake Sakakawea may also be too high.

Past predator stocking rates in Idaho waters have probably been much too high. From the hatchery data base we estimate chinook were stocked in Anderson Ranch Reservoir at 5 to 17 fish/hectare and in Salmon Falls Reservoir at 10 to 120 fish/hectare. Lake trout have been stocked in Payette Lake at 2 to 43 fish/hectare, in Palisades Reservoir at 1 to 27 fish/hectare, and in Stanley and Warm lakes at about 660 fish/hectare. Over-stocking may either result in poor or no survival of predators or depression and possibly even the collapse of the forage base (Ney and Orth 1986). Heavy predator stocking may explain the collapse of kokanee in Anderson Ranch Reservoir and the failure of chinook introductions in other Idaho waters.

Stocking rates in the past may have been determined from "typical" stocking rates for fingerling trout. For future predator introductions, we recommend adoption of conservative stocking rates to reduce initial risk and increase chances for success. Conservative stocking should result in the best possible survival of predators and maximum predator growth (Ney and Orth 1986). Once better information is available, stocking can be increased if necessary.

Management Implications

There are risks with the use of predators in kokanee waters. Kokanee populations are naturally variable and vulnerable to unpredictable forms of mortality. Reservoir drawdown, river flow, and spring warming trends have all been correlated with kokanee abundance (Mauser et al. 1988; Fraley et al. 1986; Bowles et al. 1989). The probability that kokanee production in a given water will be less than predicted is good. If forage demands in excess of forage production result from stocking on predicted forage levels, predators can depress or collapse the forage population (Ney and Orth 1986). As prey populations decline, compensation in predator growth and survival can reduce prey consumption, but probably not decline as quickly as prey abundance. Predators can impose a depensatory mortality on prey populations (Peterman and Gatto 1978; Parkinson unpublished manuscript). This can result either in collapse or a population trapped at very low densities. Kokanee may be particularly vulnerable to depensatory effects. Schooling behavior typical of kokanee may increase vulnerability to predators at low kokanee density (Clark 1974; Radovich 1979; Parkinson unpublished manuscript). Recent kokanee population collapses in Priest, Flathead, and other large western lakes have been related to lake trout predation (Beattie et al. 1990; Bowles et al. 1991). Dramatic decline of alewives in Lake Michigan and a risk of population collapse have been attributed to heavy stocking of salmonids (Stewart and Ibarra in press; Stewart et al. 1983). Aadland (1987) noted that chinook eliminated several forage species in Lake Sakakawea.

The use of predators in our least productive lakes is questionable. The benefit in predator yield relative to the cost of lost kokanee production is low. A predator fishery should produce yields of only 10% to 20% of those possible for kokanee alone. Roughly 80% to 90% (or more) of kokanee production that might otherwise be channeled to anglers or an egg-taking program is lost in conversion to harvestable production of predators. In unproductive lakes, nearly all kokanee production would produce predator yields of 0.1 to 0.3 kg/hectare. If a kokanee fishery was deemed important, predator yields would have to be even lower. By comparison, annual yield for predators in north Idaho lakes has typically ranged from 0.4 to 1 kg/hectare.

With low total fish production, there is little benefit to reduce potential yield by channeling existing production through a predator. Risks also increase with the chances for discrepancy in forage demand and production. In productive lakes, a relatively minor portion of kokanee production can be channeled to predators and still produce a good predator fishery leaving some breathing room for error. In unproductive lakes, a larger portion of production must go to

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predators to produce a similar or at least acceptable predator fishery. The risk of collapse will increase with the proportion of kokanee production channeled to predators and with the variability in kokanee abundance.

The differences in potential yield between lake trout and chinook indicate that lake trout could be a more efficient alternative in unproductive lakes. By tapping production from other fishes, particularly nongame fish, total yields can be much higher than if kokanee were the only forage. We believe, however, that the better potential associated with lake trout also equates to greater risk. Because lake trout effectively use other forage, populations can persist in the absence of kokanee. Lake trout seem to prefer kokanee. Both kokanee in the diet and lake trout growth increase as kokanee numbers increase (Mauser et al. 1988; Bowles et al. 1991). A large lake trout population can persist for long periods with forage other than kokanee but respond quickly with a dramatic increase in forage demand as kokanee populations increase. Predator inertia in lake trout is also much greater than for chinook. A strong cohort of lake trout resulting from high forage availability in one year might effect many year classes of kokanee in the future.

Limitations of the Analysis

Our results varied substantially with our assumptions about growth, mortality, and prey selection. Uncertainty in those parameters leads to uncertainty in consumption estimates that may range as much as an order of magnitude.

The uncertainty in prediction can be reduced with some familiarity with the system in question. Interpolation of our results consistent with data, or reanalysis with specific parameter estimates regarding prey selection, predator growth, and mortality will help. For example, using our base simulations, we estimated an appropriate stocking rate of about 1 chinook/hectare for Coeur d'Alene Lake. Recent experience suggests that appropriate stocking rates may be more on the order of 3 or more fish/hectare (Maiolie, Idaho Department of Fish and Game, personal communication). Available information suggests chinook mortality may be higher than we assumed in our base simulation. Incorporation of higher mortality (e.g. our assumption of poor initial survival) would roughly double the predicted stocking rate, and may be more consistent with reality. Specific information on chinook food habits and growth could produce similar corrections.

Despite the possibility of better estimates with better data, predictions of consumption and yield still are only approximations. There is uncertainty in parameters related to the bioenergetic models, to longevity, to initial size at stocking, and to temperature. Also, we did not consider the compensation that can occur in growth and survival of both predator and prey as densities vary. For example, stocking of predators will increase mortality of kokanee. As kokanee density declines, growth should increase (Rieman and Myers 1990a) with a corresponding shift in the PP:B ratio. At the same time, forage availability for predators may change with resulting shifts in growth, survival, prey selection, and conversion efficiency (Stewart and Ibarra in press). Our results best represent systems in equilibrium, although that equilibrium may never exist for very long.

We limited our work to lake trout and chinook. Additional analyses of rainbow trout, Atlantic salmon, and bull trout are possible and might be useful since those predators are also used in kokanee waters. We believe, however, that the additional work would add little new information. The basic parameters for the modeling would either be similar to, or intermediate to, those used for lake trout and chinook. Much of the necessary information on mortality, food habits, and temperature preferences is limited or not available. Our assumptions and resulting uncertainty would mirror that for chinook and lake trout. Because of the assumed consistency in bioenergetic parameters among salmonids (D. Stewart, State University of New York, personal communication), life history characteristics would have the largest effects on our results. In general, longevity for these species falls between that of lake trout and chinook. Maximum sizes are similar. Estimates of total consumption and potential yield also should be similar to those for lake trout and chinook. Predator inertia should be intermediate to the extremes. Rainbow and bull trout are known to make extensive use of invertebrate forage (Idaho Department of Fish and Game, unpublished data; Rieman and Lukens 1979; Bowler 1977) as well as kokanee. The use of alternative forage probably more closely resembles that of lake trout than chinook, particularly in earlier cohorts. We suggest then that rainbow trout, bull trout, and Atlantic salmon should provide better efficiency in yield than chinook salmon. Those species also pose greater risk for asynchrony with forage production and the chance of kokanee population collapse. The benefits and risks are probably similar to or less than those for lake trout.

Our analysis assumes that predator populations are supported entirely through hatchery stocking. In reality, predators become self-sustaining in many of the large natural lakes. In those cases, the estimates of stocking rates are of little direct benefit. Decisions to augment predator populations must rely on other estimates of existing predator consumption or kokanee mortality. Self-sustaining populations also reduce the importance of differences in predatory inertia. Natural recruitment in chinook may produce multiple generations of predators that will effect future unpredictable production of kokanee just as a single cohort of lake trout.

Despite the uncertainty in estimates of kokanee consumption and predator yield, our methods and results provide a way to evaluate management alternatives and risks. Any changes in predator management, whether it is new or enhanced stocking or a change in regulations, can at least be evaluated on a relative basis. Stocking rates can be compared to those shown here and adjusted based on experience with the system. If predators already exist in a system but present numbers are unknown, a crude approximation of current kokanee consumption can still be made from estimates of predator yield and our yield to consumption ratios. With a base of possible existing consumption and predictions for new stocking, the risk of supplementation can be weighed. The changes in consumption predicted with changes in mortality can be used to interpret the effects of fishing regulations. For example, new harvest regulations on Pend Oreille Lake should have reduced mortality on the dominant predators and, in turn, increased consumption of kokanee. A simulation of predation and the regulation changes would provide an estimate of the relative increase to be expected. Such information should be important to any decisions about further enhancement of predators in kokanee lakes.

SUMMARY AND CONCLUSIONS

Annual kokanee production ranges from about 50% to 100% of fall biomass and 75% to 150% of mean annual biomass. Production potentially available to predators ranges from about 30% to 70% of fall biomass.

Kokanee biomass (and thus production) is strongly influenced by productivity of the lake or reservoir. Potential kokanee production in Idaho waters should range more than an order of magnitude. All lakes are not equal in their potential to support fisheries or to produce forage for predators. Knowledge of lake productivity and the strength of a kokanee population is needed for decisions regarding predator introduction or augmentation.

Kokanee production represents only a part of potential forage production. Predators that use a diversity of forage have a higher potential production and yield by virtue of a larger available forage base.

Hatchery supplementation of kokanee populations could improve the portion of kokanee production that can be channeled to predators by reducing initial mortality. With complete support of the population (ie. all production is from the hatchery), the benefit could approach a two-fold increase in available forage and still maintain a stable population.

Hatchery production is often unstable. Increased predator stocking to take advantage of hatchery supplementation of kokanee could create greater discrepancy in forage demand and production. Increased predator stocking under that condition represents a greater risk of kokanee population collapse.

Our estimates of predator consumption range nearly an order of magnitude as a result of the range in our assumptions about growth, mortality, and food habits. Specific knowledge about the predators and lake in question will be necessary to make better estimates of predator consumption.

Chinook are nearly twice as efficient at conversion of total prey consumption to yield than lake trout. Lake trout, however, are likely to have more diverse food habits than chinook, resulting in better potential yield to consumption of kokanee and better yields overall. Chinook should provide the best yields in lakes where kokanee are the dominant or only forage. Lake trout will provide the best yields in systems with a diversity of fish and invertebrate forage.

Estimates of kokanee production and predator consumption are uncertain and should serve only as a starting point for adaptive management. Initial use of predators should be conservative to minimize risk and maximize survival and growth of predators. Initial stocking rates should be based on lake productivity, status of the kokanee population, and exploitation in the kokanee fishery.

Our modeling approach and results may be best used to predict relative changes in predation with changes in management. Data or educated guesses on predator growth, mortality, food habits, and stocking rates or population size can be used to approximate consumption. The effect of regulation changes or additional stocking can be estimated through the models. If direct consumption estimates are impossible, the yield to consumption ratios can be used for rough estimates of the consumption necessary to support observed yield. Consumption estimates should be related to concurrent estimates of kokanee biomass. If conservative estimates of yield to consumption ratios equal or exceed 30% of fall kokanee biomass, managers should exercise extreme caution in predator management (unless, of course, collapse of the kokanee population is not a problem).

Our estimates of appropriate stocking rates range from less than 1 to about 3 fish/hectare for chinook and to about 7 fish/hectare for lake trout. The estimates are based on our base simulations, and the best rates could be higher or lower. The estimates are consistent, however, with stocking rates in successful predator management programs. Historic stocking rates in some Idaho waters have been much higher and provide one explanation of poor performance of stocked predators and the collapse of some kokanee populations.

Longevity and diversity in food habits for Atlantic salmon and rainbow trout are probably intermediate to those for lake trout and chinook salmon. Ultimate sizes are probably similar to lake trout and chinook salmon. The potential yields of Atlantic salmon and rainbow trout per lost kokanee production should be better than for chinook salmon and equal to or less than for lake trout. The risks of collapsing the kokanee population because of ascyhcrony in forage demand and production should also be higher than for chinook salmon and equal to or less than for lake trout.

RECOMMENDATIONS

1. Initial predator stocking rates should not exceed 1 to 3 chinook/hectare or 2 to 7 lake trout/hectare based on lake productivity and kokanee densities. Stocking should only be increased based on experience with previous introductions in a system.

2. Planned yield-to-consumption ratios should not exceed 30% of fall kokanee biomass. Risk of collapse of kokanee population is high with predator numbers that utilize kokanee forage beyond this level.

3. Lake trout have a greater predatory inertia than chinook. Lake trout should also be less dependent on kokanee as forage. Lake trout represent a greater risk of *asynchrony* in forage demand and availability than chinook and a greater risk of collapsing a kokanee population for long periods. Lake trout should not be used in systems where kokanee production is highly variable.

4. Roughly 90% of kokanee production is lost by conversion to yield of predators. If all available kokanee production must go to predators to support a reasonable fishery, and if kokanee are the dominant or only forage available, the use of predators represents a major decline in potential yield to anglers. Predators should not be used in unproductive kokanee systems unless the kokanee fishery is of little value and other forage is available.

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APPENDICES

2-APPS

Appendix A. Mortality schedule for simulations used to estimate kokanee production available to predators. Mortalities and instantaneous rates were selected to produce equilibrium based on adult sex ratios of 1:1 and fecundities predicted from adult sizes.

	Base	Low Incubation	High Incubation	Low Growth	High Growth	Prey Selection	With Exploitation
Fecundity	400	400	400	250	800	400	400
Instantaneous mortality							
Egg to emergence[a]	0.91	1.61	0.44	0.91	0.91	0.91	0.91
Emergence to 0+[b]	2.30	2.30	2.30	2.30	2.30	2.30	2.30
0+ to 1+	0.70	0.47	0.86	0.40	0.93	0.90	0.70
1+ to 2+	0.70	0.47	0.86	0.40	0.93	1.10	0.70
2+ to 3+[c]	0.70	0.47	0.86	0.40	0.93	0.10	0.30
3+ to 4+[c]	0.00	0.00	0.00	0.40	0.00	0.00	0.40
Exploitation[a]	0.00	0.00	0.00	0.00	0.00	0.00	0.40

[a]Mortality to emergence and to exploitation were not included in estimates of production available to predators.
[b]All estimates are to the fall of the year.
[c]All fish were assumed to die with spawning after age 3+ except in the case of low growth where an additional year was necessary to reach a typical minimum adult size.

1-TABLES

Appendix B. Fall length (mm) and weight (g) at age[a] for simulations used to estimate kokanee production available to predators.

Age	Base Growth		High Growth		Low Growth	
	Length	Weight	Length	Weight	Length	Weight
Emergence	25	0.09	25	0.09	25	0.09
1	80	1.43	100	6.00	65	1.43
2	150	24.0	210	75	100	6.06
3	210	73	300	240	150	23
4	250	130	340	370	190	52
5	---	---	---	---	---	---

[a]Age noted as fall birthdate (e.g. age 1 fish following first summer in the lake).

PREDTBLS

Appendix C. Temperature selection[a] assumed for lake trout and chinook salmon in simulations of food consumption and conversion efficiencies.

Date	Simulation Day	Age 0 Chinook	Age 1 and older Chinook	Lake Trout
Jun 1	1	9	9	9
Jul 1	30	14	11	10
Aug 1	61	18	11	10
Sep 1	92	18	11	10
Oct 1	122	12	11	10
Nov 1	153	10	10	10
Dec 1	183	6	6	6
Jan 1	214	5	5	5
Feb 1	245	4	4	4
Mar 1	273	4	4	4
Apr 1	304	5	5	5
May 1	334	6	6	6
May 31	365	9	9	9

[a]Based on temperature preferences cited by Stewart and Ibarra (in press) and observed temperatures in Coeur d'Alene Lake.

Appendix D. Simulated prey consumption and yield per recruit for lake trout and chinook salmon under varied growth and exploition. Estimates for chinook are of total prey consumption. Estimates for lake trout are of total prey consumption and of kokanee only.

CHINOOK SALMON

	Fast Growth		Slow Growth	
Exploitation	Total Consumption (4)	Yield	Total Consumption (4)	Yield
0.00	20,450	0.0	9,200	0.0
0.13	16,675	504	7,827	247
0.24	13,920	773	6,765	388
0.42	10,352	979	5,363	514
0.62	7,047	1,010	4,012	570
0.80	5,229	992	3,218	604

LAKE TROUT

	Fast Growth			Slow Growth		
Exploitation	Total Consumption (4)	Kokanee Consumption (4)	Yield	Total Consumption (4)	Kokanee Consumption (g)	Yield
0.00	19,640	12,680	0	7,882	3,931	0
0.04	15,849	9,878	228	6,762	3,116	102
0.08	13,140	7,860	358	5,921	2,517	165
0.16	9,666	5,258	472	4,777	1,732	233
0.23	7,643	3,749	503	4,062	1,268	262
0.32	5,518	2,202	499	3,252	790	281
0.48	4,145	1,262	472	2,681	505	287

1-TABLES

JOB COMPLETION REPORT

State of: Idaho

Name: Status and Analysis of Salmonid Fisheries

Project No: F-73-R-13

Title: Kokanee Population Dynamics

Subproject No.: II

Job 2: Statewide Kokanee Inventory: Prediction of Yield

Study No.: II

Period Covered: March 1, 1990 to March 31. 1991

ABSTRACT

We created a computer data base of biological and fishery information from 78 kokanee lakes and reservoirs throughout the western states and British Columbia. Kokanee yield estimates were available for 32 of these lakes and reservoirs. Complete yield and productivity information were limited to lakes of low or intermediate productivity. Several relations exist between yield and lake productivity. Morphoedaphic index, chlorophyll 'a', and angling effort had significant positive relations with kokanee yield. MEI and chlorophyll 'a' are the best predictors of potential kokanee yield. Effort is the most important factor in determining yield. Total phosphorus is not a good estimator of fish yield for our lakes. Incorporation of both lake productivity and total effort in a multiple regression and analysis of covariance with effort as a covariate were unsuccessful. The upper limit of yields observed in our lakes should be considered the upper limit of potential yield for lakes of comparable productivity.

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RBDTEXT

INTRODUCTION

There is probably a wide range in the potential yield of kokanee _Oncorhynchus nerka_ fisheries found throughout Idaho and the Pacific Northwest region (Rieman and Myers 1990a). Fish yield can be influenced by lake productivity, kokanee population characteristics, or angling pressure. A summary of lake productivity, kokanee population characteristics, and creel census information from a variety of kokanee lakes would provide a better perspective for management decisions. If information is standardized and readily available, evaluations and comparisons could be made to develop more realistic goals for individual kokanee systems. These data may also be used for empirical estimators of potential kokanee yield or biomass.

Many estimators of fish yield have been proposed. Methods range from simple empirically-derived indices of fish production to elaborate ecosystem simulation models (Leach et al. 1987). Empirically-derived estimators of fish yield include measures of lake morphology, water chemistry, biological indices, and derived ratios such as morphoedaphic index (total dissolved solids/mean depth).

We hypothesized that potential yield (total weight harvested per lake surface area) for kokanee is primarily a function of lake productivity and, secondarily, of other physical and biological characteristics of the system. Realized yield should be a function of the potential yield and fishing effort when effort is heavy (Goddard et al. 1987). A model of potential kokanee yield should be possible given enough observations. Realized yield should be possible by incorporating effort as a variable. To be useful for the manager, the data required for the model must be easily obtained from normal physical and biological inventory. Therefore, we limited our analyses to those kinds of data.

Our objectives were:

1. to compile a standardized computer data base; and,

2. to develop empirical models that would allow the prediction of potential kokanee yield based on the characteristics of the lake or reservoir of interest.

During the first year of the project, we conducted a region-wide survey of existing biological and fishery information. We gathered agency reports and files to summarize data for Idaho lakes. We contacted fishery biologists directly when information was not published in reports. We then standardized the information and summarized it on a computer data base. We made a preliminary analysis of lake productivity measures and kokanee yield estimates to define potential yield estimators. Although the preliminary analysis showed promise, in most cases sample sizes were too small to confidently describe a relation between lake productivity and kokanee yield. During the second year of the project, we stepped up our efforts to locate missing water quality data for lakes with known kokanee yields. Four new lakes were also added to the data base.

RBDTEXT

METHODS

We compiled information on lake characteristics, the kokanee population, and the fishery from lakes and reservoirs throughout several western states and British Columbia that support kokanee populations (Appendix A). Lake characteristics include lake morphometry (surface area, volume, mean, and maximum depth) and measures of productivity (morphoedaphic index (MEI), mean summer Secchi depth, total phosphorus, and mean summer chlorophyll 'a'). Kokanee population data include estimates of kokanee abundance and growth, spawning escapement, and age-at-maturity. Harvest data include yearly estimates of kokanee yield, predator yield, and angler effort. The format of all variables and a summary of observations is outlined in Appendix B.

We entered MEI into the data base as conductivity/mean depth rather than total dissolved solids/mean depth as defined by Ryder (1965). Conductivity is strongly correlated with total dissolved solids and may be used in place of total dissolved solids (Hutchinson 1957; Ryder et al. 1974). For literature comparisons, we converted our conductivity measures to total dissolved solids as follows:

$$TDS = \frac{\text{Measured conductivity}}{1 + 0.02\ (\text{cell temperature} - 25)} \times 0.666$$

MEI was then expressed as TDS/mean depth in meters (Schlesinger and McCombie 1983).

All data came from existing files and reports or personal communication. We requested information directly from Montana Department of Fish, Wildlife, and Parks, Washington Department of Wildlife, and the Ministry of Environment in British Columbia. Data for Oregon, Utah, and Colorado lakes were taken from published literature and through personal communication. We gathered data for Idaho lakes from existing regional management reports and agency files.

In an attempt to be consistent in our data, we designated several conventions. We designated age change at the time of annulus formation in the spring. Therefore, a fish that was collected in the first summer or fall was age 0+. Likewise, a spawner maturing after the third summer or fall was age 2+. When designating age-at-maturity, if spawners were split evenly between two ages (i.e. 50% spawn at age 3, and 50% spawn at age 4), we listed the predominate age as 3.5. We requested time of sample (month) so length data could be standardized by growth projections. Lengths that we entered into the data base, however, are the actual measured lengths (mm total length) at the time of collection.

We requested ranges as well as mean values for estimates of spawning escapement, hatchery supplementation, kokanee abundance, harvest, and angler effort. Where possible, mean estimates reflect the mean of the highest five consecutive years of available data. The sample size was noted if less than five consecutive years of data were available.

Whenever possible, we calculated kokanee yield estimates (kg/hectare/ year) from harvest data (number and mean size). When mean size of fish in the harvest was given as length rather than weight, we calculated weight using the length-weight relationship for kokanee in Pend Oreille Lake.

We used dBase III Plus to set up two data files to store and manage the information. One data file, Regional.dbf, contains the majority of the information. We created three report forms that summarize lake characteristics (Appendix C), kokanee population characteristics (Appendix D), and kokanee fishery information (Appendix E) found in Regional.dbf. A second file, Dsource.dbf, contains the list of references used and sources of information (Appendix F). The sources of information are cross-referenced in Regional.dbf by number.

We summarized the total number of observations that were available in each data field. We plotted frequency distributions of the lakes summarized by total phosphorus, mean summer (May-September) Secchi depth, mean summer chlorophyll 'a', and kokanee yield for all lakes in the data base where the specific data were available.

To test our hypothesis that yield is a function of productivity and effort, we plotted yield against each of four productivity indices. We used correlation and regression analysis to examine relationships between yield (kg/hectare) and effort (hour/hectare); between yield and each of the four indices of productivity; and between effort and each index of productivity. We then stratified the data by elevation to compensate for possible differences in growing season. The distribution in elevation of the lakes with yield estimates had a break in the data at 1,000 m above mean sea level (Figure 1). Correlations of yield with MEI, total phosphorus, chlorophyll 'a', and Secchi were compared for lakes at altitudes of 51,000 m and >1,000 m with those from the whole data set.

RESULTS

The data base includes a total of 78 lakes and reservoirs and 64 data fields (Appendix B). Very few observations are complete for all 64 variables.

The 78 lakes and reservoirs that we summarized varied in surface area from 13.4 hectares to 51,039 hectares (Appendix C). Mean depth ranged from 3.0 m to 164 m. Forty-eight of the lakes are in the state of Washington, 16 are in Idaho, 4 are in Colorado, 3 each are in British Columbia and Montana, and 2 each are in Utah and Oregon. Elevations ranged from 4 m to 2,524 m above mean sea level.

Most of the lakes in the data base are relatively unproductive (Figure 2). Total phosphorus ranged from 3 ug/l to 94 Iig/l (n = 60). Total phosphorus levels in 50% of the lakes were below 18 }tg/l. Thirty percent of the lakes had

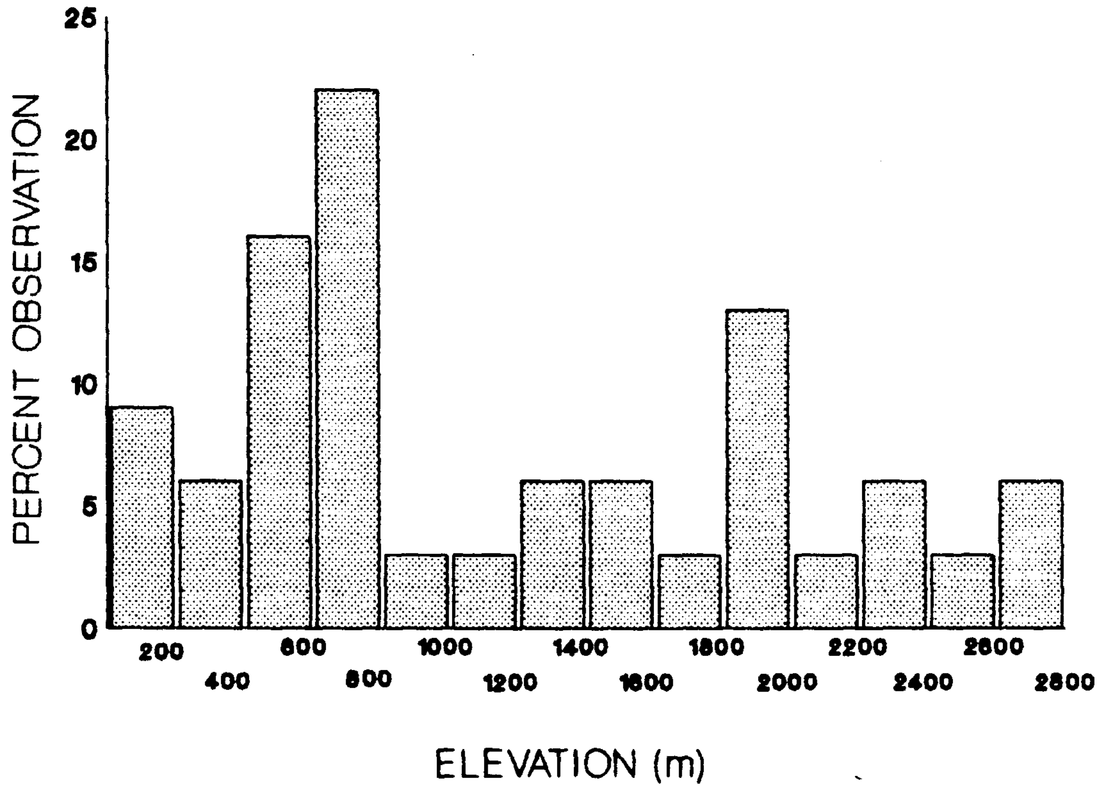

Figure 1. Frequency distribution of observations by elevation (m above mean sea level) for 32 lakes and reservoirs where yield estimates were available.

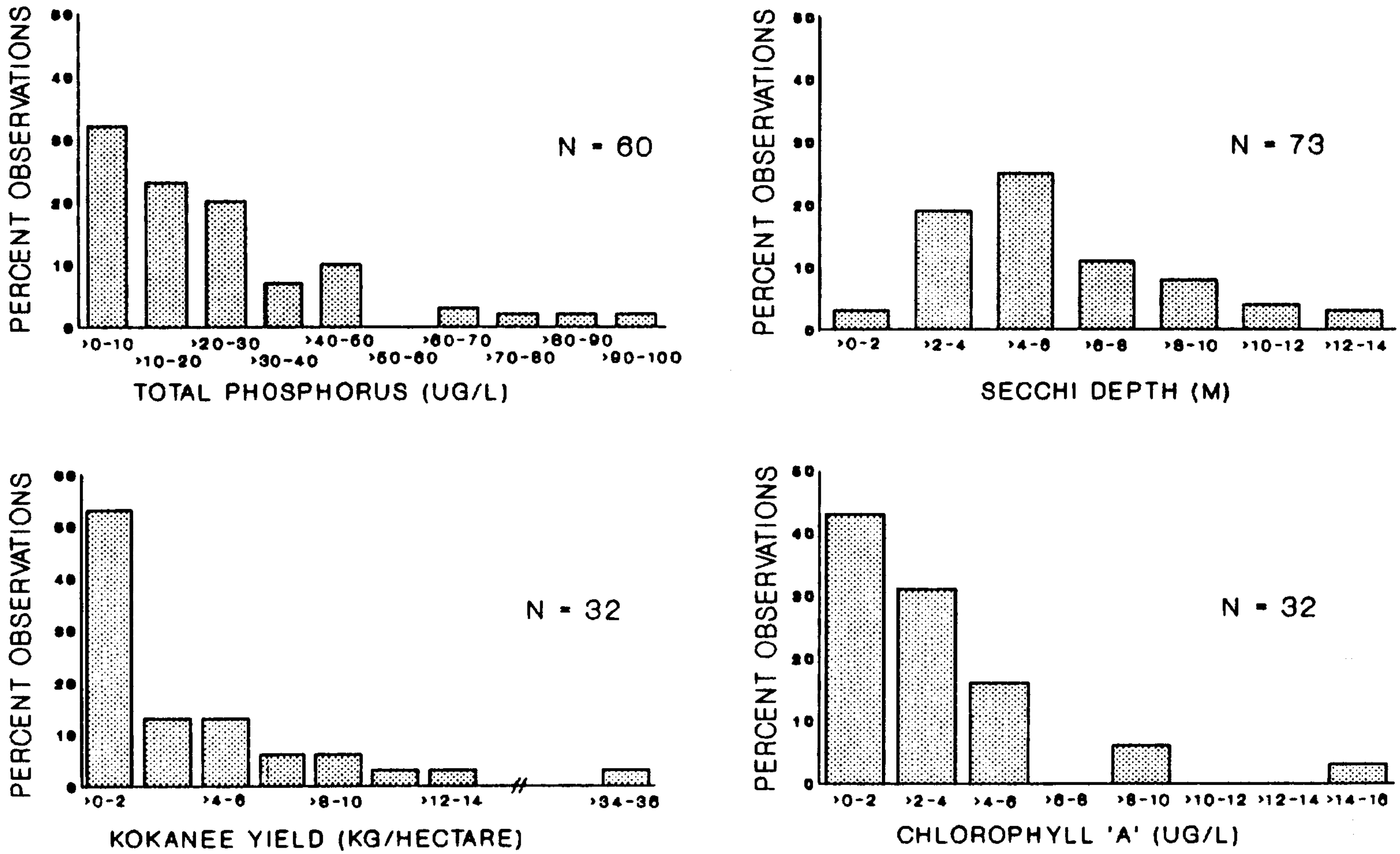

Figure 2. Ranges and distribution of observations for total phosphorus, Secchi depth, chlorophyll 'a', and kokanee yield for all lakes sampled.

total phosphorus levels <10 µg/l. Secchi depths ranged from 1.0 m to 14.0 m (n = 73), with 50% betweeen 3.7 m and 7.0 m. Chlorophyll 'a' values ranged from 0.5 µg/l to 15.0 µg/1 (n = 34), with 50% less than 2.5 µg/l.

Kokanee yield estimates were available for 32 lakes and reservoirs (Table 1). A complete list of data used in the regression and correlation analyses is in Table 2. Yield estimates with full census data ranged from 0.023 kg/hectare in Alturas Lake, Idaho (Secchi depth = 13.0 m) to 12.741 kg/hectare in Spirit Lake, Idaho (Secchi depth = 3.9 m). Fifty percent of the estimates are between 0.017 kg/hectare and 2 kg/hectare (Figure 2). Yield estimates were not available for any of the lakes with concentrations of total phosphorus and chlorophyll 'a' above 50 11g/1 and 6 ug/l, respectively. Four of the 32 yield estimates represent either exceptionally low years or partial estimates (i.e. declines following the Mt. St. Helens eruption or partial seasons) (Table 1). Two of the 32 lakes (Lake Mary Ronan and Island Park Reservoir) were excluded from the analyses as outliers.

During the first year of the study, we found a strong positive relation ($r = 0.85$, $n = 16$, $P < .05$) between total effort (rod hours/hectare) and kokanee yield (kg/hectare) (Figure 3). In the second year of the study, sample size was almost doubled ($n = 27$). We again found a significant but weaker relation ($r = 0.584$, P (.05) between total effort and kokanee yield. For some observations, we were able to determine the percent of effort targeting kokanee. We found the best correlation with yield with estimated effort targeting kokanee ($r = 0.889$, $P < .0025$). Sample size was reduced to 17 observations, however, in this last correlation.

We also found significant correlations between yield and indexes of lake productivity (Figure 3) and between effort and lake productivity (Table 3). Regression analysis incorporating both effort and a productivity index as independent variables did not provide any significant improvement in single variable models of yield.

When we divided the lakes by elevation, we found a stronger relation existed between the productivity indices and yield (Table 4). The relation between MEI and kokanee yield showed the most marked improvement ($r = 0.70$ for lakes at ≤1,000 m above mean sea level). Sample sizes for the higher elevation lakes were very low ($n = 5$ to 11). The best regression models are summarized in Table 5.

DISCUSSION

Many empirical models relating abiotic and biotic factors to total fish yield or standing crop of fish have been developed (Leach et al. 1987). MEI is a useful tool for predicting potential fish yield among lakes and reservoirs that have similar growing seasons (Ryder 1965; Jenkins 1967, 1982; Ryder et al. 1974; Henderson et al. 1973). Hanson and Leggett (1982) found total phosphorus and macro-benthos biomass and mean depth to be stronger predictors of total fish yield than morphoedaphic index. Oglesby et al. (1987) predicted walleye yield

Table 1. Kokanee yield estimates for 32 lakes and reservoirs in Idaho, Washington, Oregon, Montana, Utah, Colorado and British Columbia.

Body of water	Mean length in catch (mm)	Mean weight in catch (g)	Number harvested	Total weight (kg)	Lake surface area (hectare)	Yield (kg/hectare)	Comments
Alturas	210	71.85	107	8	339	0.023	1986-87 mean
Anderson Ranch	---	247.00	33,600	8,299	1,918	4,327	1985 only
Coeur d'Alene	215	77.74	521,517	40,544	12,743	3,182	1979-80 mean
Dworshak	258	143.13	206,976	29,624	6,920	4,281	1988 only
Island Park	330	326.25	158	52	3,153	0,016	winter fishery only[a]
Payette	288	206.84	1,276	264	2,160	0,122	1987-88 mean
Pend Oreille	245	120.38	838,460	100,935	38,348	2,632	1958-1962 mean
Priest	---	140.00	84,131	11,778	9,454	1,246	1968-1970 mean
Redfish	240	112.35	1,400	157	608	0,259	1986-87 mean
Spirit	245	128.10	59,480	7,619	598	12,741	1981 only
Stanley	194	55.11	150	8	74	0,112	1986 only
Banks	364	453.02	60,740	27,516	11,008	2,500	7 year mean
Billy Clapp	260	146.88	6,126	900	405	2,222	1978 only
Chelan	285	199.72	6,000	1,198	13,355	0,090	represents decline
Deer	411	680.24	584	397	445	0,893	1938-40 mean
Loon	387	556.15	584	325	457	0,711	1938-40 mean
Merwin	300	327.13	4,693	1,113	1,619	0,687	1978-82 mean
Sammami sh	---	442.00	359	159	1,982	0,080	represents decline
Yale	305	250.62	10,919	2,737	1,538	1,779	represents decline
Arrow	250	128.80	13,600	1,751	28,000	0,130	5 year mean
Kootenay	---	90.00	50,000	4,500	38,900	0,116	5 year mean
Okanagan	---	174.00	156,000	27,144	35,112	0,773	1971, 1978-80 mean
Flathead	312	270.00	495,910	134,095	51,039	2,627	1981-82
Mary Ronan	269	164.60	129,625	21,336	602	35,442	1989
Libby/Koocanusa	307	256.17	29,480	7,552	18,160	0,416	1987
Flaming Gorge	---	623.00	30,294	18,873	17,000	1,110	1985-88
Porcupine	---	300.00	1,580	474	80	5,925	1979 only
Dillon	276	179.38	67,575	12,121	1,300	9,324	1975-79 mean
Green Mountain	351	401.09	14,200	5,696	850	6,701	1975-79 mean
Granby	317	285.18	58,000	16,541	2,938	5,630	1975-79 mean
Odell	---	230.00	64,000	14,720	1,454	10,124	
Wallowa	236	106.21	25,982	2,759	610	4,524	1987-90 mean

[a]partial estimate--excluded from regression analysis.

2-TABLES

Table 2. Characteristics of lakes and fisheries used to examine relationships with kokanee yield.

Body of water	Elevation (m)	Secchi Depth (m)	Conductivity	MEI	Total phosphorus (uq/l)	Chlorophyll 'a' (uq/1)	Total effort (h/ hectare)	Kokanee effort (h/ hectare)	Yield (kg/ hectare)
Alturas	2140	13.0	49	1.3	9	---	33.46	---	0.023
Anderson Ranch	1280	3.4	60	2.1	14	4.2	45.13	38.81	4.327
Coeur d'Alene	649	5.0	80	3.3	45	4.0	19.62	18.25	3.182
Dworshak	488	4.6	30	0.5	21	4.4	15.71	9.58	4.281
Island Park[a]	1920	2.6	150	30.0	44	5.7	17.29	---	0.016
Payette	1524	9.0	20	0.5	6	1.0	8.73	1.13	0.122
Pend Oreille	629	6.5	180	1.1	11	2.0	9.27	6.49	2.632
Priest	652	8.2	50	1.3	4	1.5	6.25	---	1.246
Redfish	1996	14.0	---	0.5	6	---	23.00	---	0.259
Spirit	686	3.9	240	22.0	18	5.3	118.02	92.05	12.740
Stanley	1984	11.0	---	---	---	---	153.05	-----	0.112
Banks	479	3.0	112	8.3	49	2.6	16.93	14.56	2.500
Billy Clapp	407	2.5	165	8.3	33	---	28.42	25.58	2.222
Chelan	339	13.0	50	0.3	3	0.7	-----	-----	0.090
Deer	755	6.3	79	5.0	30	---	-----	-----	0.893
Loon	726	6.1	148	10.0	30		-----	-----	0.711
Merwin	73	5.0	---	----	--	---	18.05	9.02	0.687
Samnamish	8	4.0			21	3.4	16.85	6.24	0.080
Yale	149	6.0			--	---	15.49	11.31	1.779
Arrow	441	4.0	120	1.1	4	0.8	0.56	0.19	0.130
Kootenay	530	8.0	125	1.3	6	1.5	3.34	0.84	0.120
Okanagan	341	8.9	280	3.7	10	1.6	5.69	2.85	0.773
Flathead	882	7.0	---	---	5	---	11.76	9.76	2.627
Mary Ronan[a]	1128	4.5		13.7	--	---	59.74	53.77	35.440
Libby/Koocanusa	749	4.0	255	6.7	17	3.0	20.95	20.11	8.596
Flaming Gorge	1841	3.6	710	20.9	30	4.2	19.29	---	1.110
Porcupine	1615	2.1	---	----	--	---	183.23	-----	5.925
Dillon	2750	---	---	---	---	---	161.54	---	9.324
Green Mountain	2423	---	---	---	---	---	147.06	---	6.701
	2524	---	---	---	---	---			
Granby		5.0	---			---	46.16	---	5.630
Odell	1459	8.1	32	0.8		2.9	107.98	78.82	10.12
Wallowa	1336	11.0	93	1.3		1.9	37.76	---	4.50

[a]Island Park and Mary Ronan were excluded from regression analysis.

2-TABLES

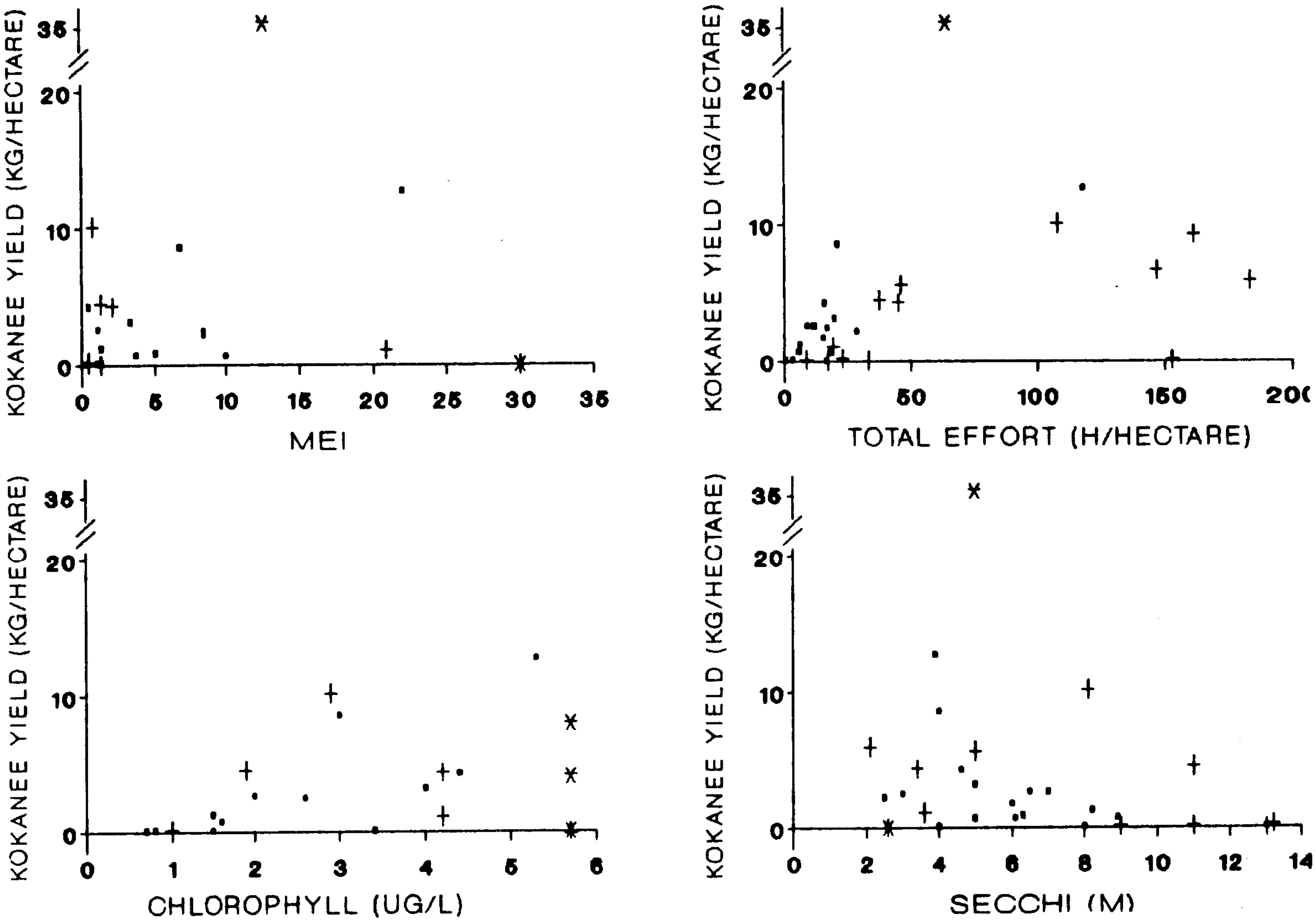

Figure 3. Relations of three productivity indices and total effort to kokanee yield for all lakes sampled. Crosses represent lakes at elevation >1000 m; dots represent lakes at elevation ≤1000 m; Asterisks represent data outliers that were excluded from analysis (Island Park Reservoir and Lake Mary Ronan).

Table 3. Correlation coefficients for whole data set. Asterisk denotes significant correlations (a = 0.05). Sample size in parentheses.

	Yield	Secchi depth	MEI	Total phosphorus	Chlorophyll 'a'	Total effort	Kokanee effort
Yield	1.000						
Secchi depth	-0.370 (28)	1.000					
MEI	0.326* (20)	-0.498 (20)	1.000				
Total phosphorus	0.099 (21)	-0.577* (21)	0.417* (17)	1.000			
Chlorophyll 'a'	0.524* (17)	-0.647* (17)	0.620* (16)	0.550* (14)	1.000		
Total effort	0.584* (27)	-0.051 (25)	0.398* (17)	0.090 (18)	0.545* (16)	1.000	
Kokanee effort	0.889* (17)	-0.162 (17)	0.617* (13)	0.143 (13)	0.621* (13)	0.990* (18)	1.000

2-TABLES

Table 4. Correlation coefficients of four productivity indices with yield using a data stratified by elevation. Asterick denotes r values at 95% confidence. Sample size in parentheses.

	Elevation < 1,000 m	All Observations	Elevation > 1,000 m
MEI	0.701* (14)	0.326* (20)	0.290 (6)
Total phosphorus	0.089 (16)	0.099 (21)	-0.037 (7)
Secchi depth	-0.416* (18)	-0.370* (28)	0.381 (11)
Chlorophyll 'a'	0.656* (12)	0.524* (17)	0.155 (5)
Log MEI	0.498* (14)	0.255 (20)	-0.306 (6)
Log total phosphorus	0.221 (16)	0.232 (21)	-0.289 (7)
Log Secchi Chlorophyll 'a'	-0.409* (18)	-0.362* (28)	-0.389 (10)
Log Chlorophyll 'a'	0.572 (12)	0.508 (17)	0.309 (5)

2-TABLES

Table 5. Best regression models for yield (kg/hectare) and four measures of productivity.

Beg-ession formula	n	r^2	P	Data set used
Yield = 0.424 MEI + 0.850	14	0.49	0.002	elevation ≤1,000 m
Log Yield = 1.483 log Chlorophyll - 0.842	17	0.29	0.013	all observations[a]
Yield = 1.736 Chlorophyll - 1.236	12	0.43	0.010	elevation ≤1,000 m
Log Yield = 2.150 - 0.303 Secchi	28	0.36	0.001	all observations[a]
Log Yield = 2.067 - 0.310 Secchi	18	0.32	0.009	elevation ≤1,000 m
Yield = 0.37 total effort + 1.751	27	0.34	0.001	all observation[a]

2-TABLES

using chlorophyll 'a' concentration as the independent variable. Schlesinger and McCombie (1983) found angling effort proved to be the best single independent variable in predicting yield. Effort and MEI in combination improved the correlation.

Lake productivity data that were the most easily obtained for our data set were MEI, total phosphorus, mean summer chlorophyll 'a', and mean summer Secchi depth. Measures of macro-benthos biomass are not readily available from normal lake inventory records. Zooplankton biomass, which would be a more logical choice for use in kokanee lakes because of their close association to kokanee, also is not readily available. Therefore, neither macro-benthos or zooplankton biomass were considered in our analysis.

Morphoedaphic Index

MEI was originally described as a quick and convenient method of estimating potential fish yield from large north-temperate lakes at altitudes <600 m (Ryder et al. 1974). Since its first description, MEI has been used as a yield or biomass estimator for lakes and reservoirs belonging to several different systems throughout the world (Jenkins 1967; Ryder et al. 1974). The criteria that Ryder et al. (1974) set up for the identification of lakes suitable for regression of yield on MEI are: 1) similar climatic conditions, 2) similar ionic composition of dissolved material, 3) proportional flushing rates per unit of lake volume, 4) inorganic turbidity on the same order of magnitude for all lakes, and 5) moderate to intense fishing effort over several years.

Our data suggest that MEI can be a useful estimator of potential kokanee yield in lower elevation (≤1,000 m) lakes and reservoirs ($r = 0.49$; $P < 0.0025$). Correlations of yield with MEI for the entire data set, however, resulted in a much lower r^2 (0.11). This lower value may be caused by a violation of Ryder's criteria for the use of MEI when it is applied to the entire range of our data set. Careful consideration of climate or growing season, ionic content of the water, and exploitation levels may lead to more accurate use of MEI as a predictor.

When we plotted MEI (expressed as TDS/mean depth in m) and kokanee yield for lakes ≤1,000 m with other MEI-fish yield relations found in the literature (Matuszek 1978; Schlesinger and McCombie 1983), we found Idaho lakes had similar yields relative to MEI (Figure 4). The slope of our regression line (not shown) is steeper than either of the two lines, probably because our sample size is small ($n = 14$). Our data also represents some lakes which were not fully exploited. A larger sample size with consideration of effort and MEI in combination may explain this variation.

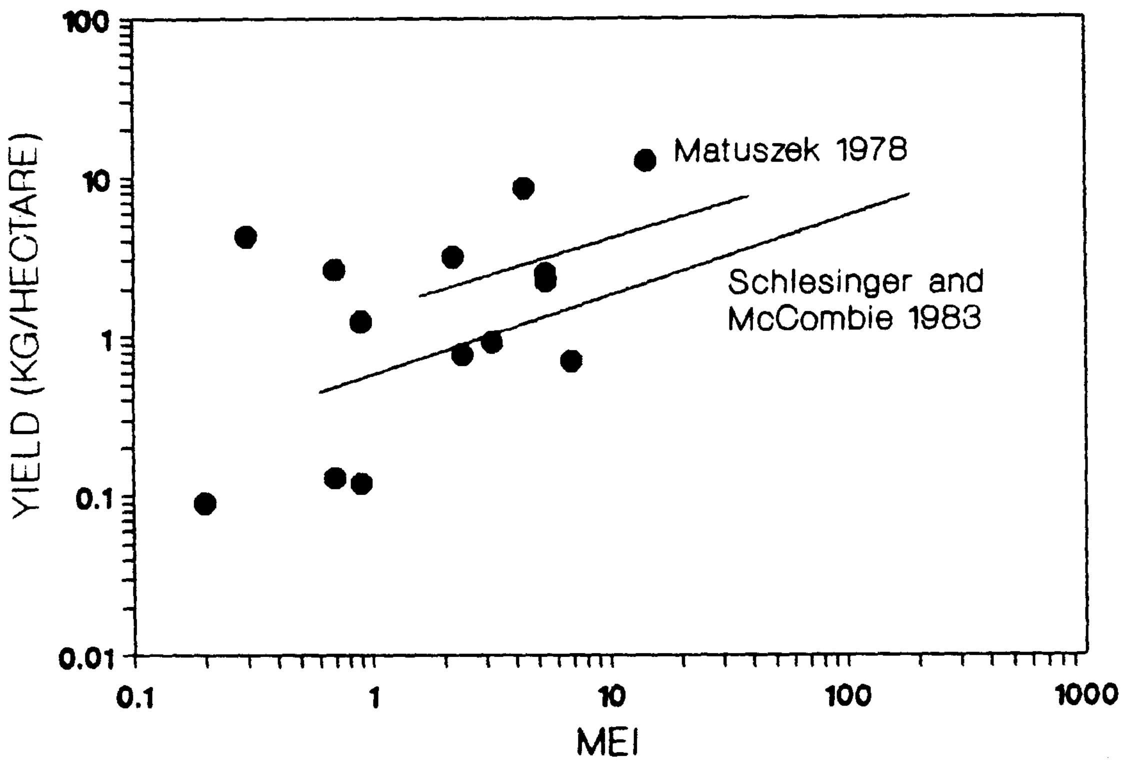

Figure 4. Comparison of MEI and kokanee yield estimates for the Idaho data set, lakes at ≤1000 m, with MEI and total fish yield estimates found in the literature.

Total Phosphorus

Our data show total phosphorus to be a poor predictor of fish yield in all instances. The relation between phosphorus and chlorophyll '.a' can be highly variable (Hoyer and Jones 1983). Confidence limits associated with predictions of chlorophyll from total phosphorus are wide (Dillon and Rigler 1974). Inorganic suspended solids, lake flushing rates, and zooplankton community structure have been cited for causes of variation in the total phosphorus-chlorophyll relation' (Oglesby 1977; Hoyer and Jones 1983; Pace 1984; Edmundson and Koenings 1986; Ostrofsky and Rigler 1987). The use of total phosphorus alone as a predictor of potential yield may be inappropriate in situations where a large amount of the total phosphorus consists of biologically unavailable phosphorus that is adsorbed to soil particles (Oglesby 1977). Edmundson and Koenings (1986) found that dissolved phosphorus (biologically available) levels ranged from a low of 9% of the total phosphorus in highly turbid systems (40 NTU) to 56% in lakes with low turbidity (NTU <10). High flushing rates may be responsible for removing phytoplankton from the system before they reach their maximum level (Oglesby 1977; Hoyer and Jones 1983). Flushing rates in our data ranged from 0.02 to 11 years in lakes where yield data were available. Large zooplankton filter algae at a much more efficient rate than small zooplankton (Shapiro 1980). Mills and Schiavone (1982) found zooplankton size was related negatively to chlorophyll 'a'. Lakes dominated by large zooplankton should have less chlorophyll per unit total phosphorus than lakes dominated by small zooplankton (Pace 1984).

Chlorophyll 'a'

We found a significant positive relation between chlorophyll and kokanee yield ($r^2 = 0.430$, $P < 0.05$) for lakes <1,000 m. Oglesby et al. (1987) found regression of walleye and total fish yield on mean growing season chlorophyll 'a' concentration indicated strong positive correlations ($r^2 = 0.81$ and 0.73, respectively). Jones and Hoyer (1982) also found significant relation between chlorophyll and fish yield in midwestern lakes and reservoirs. These systems were much more productive than those in the Idaho study (mean chlorophyll 'a' = 28 ug/l). In our regression analysis, chlorophyll 'a' values ranged from 0.7 to 5.7 ug/l.

Chlorophyll 'a' concentration is closer trophically to kokanee than total phosphorus; it should, therefore, prove to be a better overall indicator of potential yield. Chlorophyll 'a' is more difficult and costly to measure than either MEI or Secchi transparency. Comparisons with other lakes or reservoirs is difficult because chlorophyll levels in our sample lakes are extremely low compared to those reported in the literature. Chlorophyll data from more productive lakes than those that dominated our observation might improve the relationship.

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Mean Summer Secchi Depth

Mean summer Secchi depth is the variable most easily obtained (n = 28). Secchi transparency showed significant inverse relationships with MEI, total phosphorus and chlorophyll 'a', and a relationship with kokanee yield (r^2 = -0.36; P <0.001). Kokanee growth is related to lake productivity as expressed by Secchi transparency or chlorophyll 'a' (Rieman and Myers 1990b). Because Secchi transparency correlates well with other productivity indices and with kokanee growth, it should be a good choice as an overall indicator. A larger sample size, however, is needed to more accurately describe its relationship to kokanee yield. Again, more observations from more productive lakes may help.

Effort

Effort undoubtedly has a large influence on kokanee yield and may explain much of the variability in our relationships of productivity and yield. The positive relation between effort and yield was similar to that found for other fishes (Jenkins and Morias 1971; Schlesinger and McCombie 1983; and Goddard et al. 1987). Effort also correlated strongly with MEI and chlorophyll 'a'. Separation of lake productivity and angling effort is difficult. If angling effort is responsive to success or failure, then observed effort, rather than observed yield, will tend to correlate with the basic productivity of the population (Goddard et al. 1987). Multiple regressions or analysis of covariance incorporating both productivity and effort, however, did not prove to be useful in our case. The observations may be too limited in range and number to effectively incorporate both variables.

SUMMARY AND CONCLUSIONS

We have summarized a substantial amount of information on kokanee fisheries in a form accessible for kokanee management. The relations we found between lake productivity measures and fish yield show promise for their use in developing predictive tools for kokanee populations in the northwest. Most observations, however, are incomplete. Complete yield and productivity information are limited to lakes of low or intermediate productivity. In some cases, literature comparisons are difficult because our data set is composed mostly of oligotrophic systems. Many empirically derived estimators of fish yield found in the literature are based on much more productive lakes and reservoirs.

MEI and chlorophyll 'a' are the best individual estimators of potential kokanee yield. Effort appears to be the most important factor in determining actual yield. Incorporation of both productivity and effort in a multiple regression to predict actual yield was not successful. Colinearity between productivity and effort may complicate the analysis. Other factors may also be important. Environmental limitations, or the presence of predator or competitive species probably affect yield. Stocking rates also vary among lakes. Given

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this, the upper limits of our points may best represent the potential of a system. For lakes with yields substantially below the potentials suggested here, managers should examine alternative explanations for low yields. Lakes with fishing effort less than 80 rod hours/hectare may be underexploited.

The relationships we found between lake productivity and kokanee yield show promise for their use in developing a valuable tool for the management of fish in Idaho. More useful empirical models will require observations over a wider range of lake productivity. More observations may also allow the incorporation of several independent variables such as flushing rates, stocking rates, turbidity, and length of growing season.

RECOMMENDATIONS

1. Long-term monitoring and inventory of kokanee fisheries should include chlorophyll a, Secchi depth, MEI, and fishing effort as the best potential predictors of kokanee yield. The use of phosphorous concentrations may be confounded by variation in the biologically available form, flushing rate, and zooplankton community structure.

2. The observations summarized in this report are too few or incomplete to incorporate these variables in a predictive model. More (and more complete) observations should include estimates of kokanee yield, total effort, and the parameters discussed in Recommendation 1 for any new inventory of a fishery whenever possible.

3. The upper limits of yields observed in our lakes should be considered the upper limits of potential yield for lakes of comparable productivity (Table 1). In the absence of more complete information, the data summarized here can provide a perspective for kokanee fisheries management goals.

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ACKNOWLEDGMENTS

Several people were instrumental in compiling the information for the regional data base. Steve Jackson and Eric Hagen, Washington Department of Wildlife, and Bruce Sheperd and W.T. Westover, British Columbia Ministry of Environment, each contributed substantial information to the data base. Stan Allen provided consultation on dBase structure and dBase-related problems.

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APPENDICES

Appendix A. Summary forms used for data collection.

2-APPS

LAKE: ....

State or Province ....

LAKE CHARACTERISTICS:

Elevation, (meters above sea level): __________ Latitude: __________

Drainage Basin Area (sq.km): __________ Maximum Depth (m): __________

Lake Surface Area at Full Pool (ha): __________ Mean Depth (m): __________

Shoreline Length (km): __________ Volume: __________

Theoretical Flushing Rate (lake volume/mean annual outflow): ______________

Mean Depth of Thermocline (top of thermocline) in August: ______________

Total Phosphorus at Spring Overturn, Expressed as P (ug/l): ______________

TDS (mg/l): ____________ OR Conductance (umhos/cm^2 at 25°C): __________

(ɔrophyll "a" (ug/l): __________ (mean) __________ (range) ______________ (sampling period for mean, i.e., annual, May-Sept.)

Secchi Depth (m): __________ (mean) __________ (range) ______________ (sampling period for mean, i.e., annual, May-Sept.)

COMMENTS: (include other observations that can help define productivity or trophic status, i.e., C^{14} estimates, oxygen deficits, common algal blooms, winter kill)

MAJOR PERTURBATIONS TO THE SYSTEM:

Physical

Drawdowns (annual range in meters): __________________________

Month(s) largest reduction in lake surface elevation occurs: ________________________

C ENTS: (other major perturbations or problems: dams on tributaries, blocked spawning habitat, entrainment of fish via water release points, or other important changes and relative significance of the problem)

Biological

Mysis (Y/N): ____________ Year Mysis Introduced: ________

Density Range ($\#/m^2$): ____________ Year Obviously Established: ________

COMMENTS: (other biological perturbations, macrophytes (milfoil), other invertebrates (common name), cultural eutrophication, ...)

KOKANEE POPULATION:

Introduced or Native: ____________ Year 1st Introduced ____________

Source lake if introduced (original native stock if known): ________________

Predominant age of spawning fish:

Fish that spawn after the third summer are considered to be age 2+
If split evenly between two ages, i.e. 3 and 4, list as 3.5.

Range: ________________ Dominant: ____________

Peak spawning time (mode of temporal distribution): ____________________ month(s)

L..gth at Age:

Note method of estimate (scale back calculation, otolith, length frequency).
If length does not represent size-at-annulus formation, note the month of sample and place a plus (+) after the age (i.e., during first summer/fall, age = 0+);
Range is for all fish in all years.

Method of Estimate: ____________ Month of Sample: ________________

Age	Length (mm) Mean	Range	Mean of all yrs.
0			
I			
II			
III			
IV			
V+ & older			
Spawners			

COMMENTS: (obvious density dependence, differences in growth between males and females)

<u>Abundance:</u> Population number or density (no/ha). For "Mean of 5 years" give *mean* of highest 5 consecutive years. If less than 5 consecutive years are available, note the sample size.

Total Number: Range:___________________ Mean of 5 years:

Method of Estimate (trawl, acoustics...): ______________

Total Adult Number (escapement plus harvest of mature fish):

Range: ___________________ Mean of 5 years: _______________

Method(s) of Estimates _________________________________

COMMENTS:

Management: Number stocked. For "Mean of 5 years" give mean of highest 5 consecutive years. If less than 5 consecutive years of data are available, note the sample size. For "Time of release" give month targeted for peak release. For "Percent contribution" give the percent of the population from hatchery production in years of maximum hatchery release.

Number stocked annually: Range:____________________ Mean of 5 yrs.: __________

Size at release (mm): Range:___________________ Mean:____________________

Time of release (month):____

Contribution of hatchery vs. wild (%):____

COMMENTS: (special management, research, or fishery development programs - include such things as long term monitoring, fertilization, and experimental releases ...)

FISH COMMUNITY

r': Species (Common Name): ______________________________

COMMENTS: (estimates of escapement or density, relative importance of predator, relative effect on kokanee...)

Qther Fish: List all species (common name): ______________________________

____

____

____

COMMENTS: (relative abundance, estimates of density, interaction with kokanee...)

FISHERY

Total Angler Effort: (Rod hours/year) estimated hours for a full season. For "Mean of 5 years" give mean of highest 5 consecutive years. If less than 5 consecutive years of data are available, note the sample size.

Range: ______________________________

Mean of 5 Years: ______________________________

COMMENTS: (Note if census does not represent all angler effort or full season - if estimate is in days, provide an estimate of the length of an angler day).

Percent Effort
Targeting Kokanee: (What percent of the total estimated effort is by anglers specifically targeting kokanee?) For "Mean of 5 years" give highest 5 consecutive years. If less than 5 consecutive years of data are available, note sample size.

f

Range: ______________________ Mean of 5 Years: ______________________

____

COMMENTS :

Catch Rates: (preferably fish per rod hour; if by rod day, provide an estimate of the length of a day)

S e e r mean: ____________ Annual mean: ____________

Primary Method: ______________________
(trawl, handlines, other)

COMMENTS:

Kokanee Harvest: Total *number* of fish in the catch of all fishermen for the whole lake. For "Mean of 5 years" give highest 5 consecutive years. If leas than 5 consecutive years of data are available, *note* sample size. For "Mean size in catch" provide the mean weight of fish in catch during the above period.

Range: ______________________

Mean of 5 Years: ______________________

Mean Size in Catch (g): ______________________

COMMENTS: (peak season, methods, causes of variability, long term declines...)

Predator Harvest:: Total number of fish in the catch of all fishermen for the whole lake. For "Mean of 5 years" give high.=st 5 cons utive years. If less than consecutive years of data are available, note sample size. For "Mean size in catch" provide the mean weight of fish in catch during the above 5 years.

Range: ____________________

Mean of 5 Years: ____________________

Mean Size in Catch (g): ____________________

COMMENTS: (peak season, methods; causes of variability, long term declines ...)

REGULATIONS

Seasons: ____________________

Daily Bag Limits: ____________________

____

COMMENTS:

KEY REFERENCE(S) FOR THIS LAKE

Person: ____________________ phone: ____________________

Publication(s) or Report(s): ____________________

INFORMATION SUMMARIZED BY: ____________________

Appendix B. Data structure for regional.dbf.

DATA STRUCTURE FOR DATABASE: REGIONAL.DBF

FIELD NAME	FIELD TYPE	WIDTH	DEC	DESCRIPTION OF DATA	NUMBER OF OBSERVATIONS
WATER	CHARACTER	15		LAKE NAME	78
CODE	CHARACTER	4		LAZE MANE CODE FOR **USE** IN SYSTAT	78
STATE	CHARACTER	2		STATE	78
ILI?	CHARACTER	4		ELEVATION (MITERS)	78
LATITUDE	CHARACTER	6		LATITUDE	69
DRAINAGE	CHARACTER	8	1	DRAINAGE BASIN ARIA (KN2)	69
SA	CHARACTER	8	1	**SURFACE** AREA (HA)	78
SHORELINE	CHARACTER	5	1	SHORELINE LENGTH (I N)	68
MAIDEPTH	CHARACTER	5	1	MAXIMUM DEPTH (N)	74
MEANDEPTH	CHARACTER	5	1	MEAN DEPTH (M)	78
VOLUME	CHARACTER	8		VOLUME (ACRE FLIT)	76
FLUSHRATE	CHARACTER	6	3	**FLUSH** RATE (YR)	47
THERMOCLIN	CHARACTER	2		TOP OF THERMOCLINE (N)	46
NII	CHARACTER	3	1	MORPHOEDAPHIC INDEX	62
TP	CHARACTER	3		TOTAL **PHOSPHORUS** (UG/L)	60
CONDUCT	CHARACTER	3		CONDUCTIVITY	63
CHLORS	CHARACTER	4	1	CHLOROPHYLL "A" (UG/L)	34
SICCHI	CHARACTER	4	1	SECCHI DEPTH (M)	73
DOOWN	CHARACTER	5	2	ANNUAL MEAN DRAW DOWN (M)	30
DOWNJOS	CHARACTER	10		MONTH(S) OF DRAWDOWN	21
TRIBOANS	CHARACTER	1		**DINS** ON **TRIBUTARIES** (Y/N)	19
NYSIS	CHARACTER	1		MYSIS PRESENT (Y/N)	70
NYSISS	CHARACTER	4		MYSIS ABUNDANCE (RANGE - HIGH)	
MYSIS_L	CHARACTER	4		MYSIS ABUNDANCE (RANGE - LOW)	
MYSISSS?	CHARACTER	4		YEAR MYSIS ESTABLISHED	7
KOKSOURCE	CHARACTER	15		SOURCE OF KOKANEE	53
SPAWNJOS	CHARACTER	20		PEAK SPAWNING MONTHS	22
AGIJATURH	CHARACTER	3	1	AGE AT MATURITY (.5 IF SPLIT)	23
LN 0	CHARACTER	3		MEAN LENGTH AT AGE 0+ (MN)	8
LNI	CHARACTER	3		MEAN LENGTH AT AGE If (MN)	16
LNII	CHARACTER	3		MEAN LENGTH AT AGE II+ (NM)	27
0 _111	CHARACTER	3		MEAN LENGTH AT AGE III+ (MN)	23
LM IV	CHARACTER	3		MEAN LENGTH AT AGE IV+ (MN)	12
MONTH	CHARACTER	9		MONTH OF SAMPLE **FOR** LENGTH AT AGE	17
[U P O N	CHARACTER	3		MEAN LENGTH OF SPAWNERS (MN)	9
ISCAPSI	CHARACTER	6		ESCAPEMENT TO SPAWN (RANGE - HIGH)	1
ESCAPSO	CHARACTER	6		ESCAPEMENT TO SPAWN (RANGE - LOW)	1
ESCAP_IIAN	CHARACTER	6		ESCAPEMENT TO SPAWN (MEAN)	1
ESCAPJTB	CHARACTER	10		METHOD FOR ESTIMATING ESCAPEMENT	1
TRIB SPAWN	CHARACTER	2		PERCENT TRIBUTARY SPAWNERS	0
STOCKID.HI	CHARACTER	7		NUMBER STOCKED PER YEAR (RANGE - HIGH)	20
STOCKEDI,O	CHARACTER	7		NUMBER STOCKED PER YEAR (RANGE - LOW)	16
STOCKEDT	CHARACTER	7		NUMBER STOCKED PER YEAR (MEAN)	20
STOCI TIME	CHARACTER	10		MONTH STOCKED	27
HATCHERY C	CHARACTER	2		PERCENT HATCHERY CONTRIBUTION	0

FIELD NAME	FIELD TYPE	WIDTH	DEC	DESCRIPTION OF DATA	NUMBER OF OBSERVATIONS
				-	
NOSOLANEE	CHARACTER	3		MEAN LOLANEE ABUNDANCE (NO/HA)	14
N O S O L H I	CHARACTER	4		KOKANEE ABUNDANCE (NO/HA) (RANGE - HIGH)	12
NOSOI.LO	CHARACTER	3		KOKANEE ABUNDANCE (NO/HA) (RANGE - LOW)	12
PREDATORS	KENO	10		**PREDATOR SPECIES**	
SPECIES	RENO	10		SPECIES COMPOSITION	
EFFORT	CHARACTER	6		TOTAL FISHING EFFORT (ROD **HOURS)**	28
EFFORTHI	CHARACTER	6		**TOTAL FISHING EFFORT (RANGE - HIGH)**	7
EFFORT_10	CHARACTER	6		**TOTAL FISHING EFFORT (RANGE - LOW)**	7
EFFORTSOL	CHARACTER	2		PERCENT OF EFFORT TARGETING KOKANEE	19
YIELDSOL	CHARACTER	6	3	KOKANEE YIELD (KG/HA)	32
HARVESTS	CHARACTER	6		**MEAN NUMBER** OF KOKANEE HARVESTED	33
HARVEST HI	CHARACTER	6		**NUMBER** OF **KOKANEE HARVESTED (RANGE - HIGH)**	7
HARVEST_LO	CHARACTER	6		NUMBER OF KOKANEE **HARVESTED (RANGE - LOW)**	7
LOL SIZE	CHARACTER	3		**MEAN SIZE OF KOKANEE IN THE CATCH (G)**	32
PHARVEST	CHARACTER	6		**MEAN NUMBER OF PREDATOR SPECIES HARVESTED**	13
P **_SIZE**	CHARACTER	4		MEAN SIZE OF PREDATOR IN THE CATCH (G)	4
YIELD_PRED	CHARACTER	6	3	PREDATOR YIELD (KG/HA)	4
REG	MEMO	10		REGULATIONS	
REFJO	CHARACTER	42		**CROSS REFERENCE** TO **INFORMATION SOURCE**	78

Appendix C. Summary report of lake characteristics.

2-APPS

REGIONAL DATA BASE
LAKE CHARACTERISTICS

BODY OF WATER	ST	LAT	ELEV (M)	DRAIN AREA (KM2)	SURFACE AREA (HA)	SHORE LENGTH (KM)	MAX DEPTH (M)	MEAN DEPTH (M)	VOLUME (ACFT)	FLUSH RATE (YR)	THERMO-CLINE (M)	TOTAL PHOS. (UG/L)	COND	CHLOR "A" (UG/L)	SECCHI DEPTH (M)	DRAW DOWN (M)	MYS Y/N	MEI
** BC																		
KOOTENAY	BC	494000	530	45584.0	38900.0	---	154.0	94.0	----	1.800	20	---	125	1.5	8.0	5.00	Y	0.3
OKANAGAN	BC	495200	341	6040.0	35112.0	270.0	242.0	76.0	19941634	---	15	10	280	1.9	8.9	1.00	Y	3.7
UPPER ARROW	BC	500000	441	----	28000.0	113.0	293.0	107.0	----	3.800	15	4	105	0.8	4.0	21.00	Y	1.0
** CO																		
DILLON RES.	CO	-----	2750	----	1300.0	---	60.0	23.0	248270	---	--	---	---	----	----	6.00		---
GRANBY	CO	-----	2524	1023.0	2938.0	64.4	61.0	22.6	544632	---	10	14	---	----	5.0	28.60	Y	---
GREEN MOUNTAIN	CO	-----	2423	----	850.0	---	---	22.0	154660	---	--	---	---	----	----	18.00		---
SHADOW MOUNTAIN	CO	-----	2551	1023.0	749.0	---	---	3.0	18431	---	3	23	---	----	4.3	----		---
** ID																		
ALTURAS	ID	435500	2140	85.0	339.0	8.0	67.0	38.0	77577	---	7	9	49	----	13.0	----	N	1.3
ANDERSON RANCH	ID	432330	1280	2536.0	1918.0	7.0	67.0	29.8	493000	0.657	6	14	60	4.2	3.4	19.00	N	2.0
COEUR D'ALENE	ID	474000	649	9576.0	12743.0	202.0	61.0	24.0	2479183	0.550	22	45	80	4.0	5.0	2.00	N	3.3
DEADWOOD	ID	441930	1618	290.0	1295.0	17.0	30.0	15.0	160600	0.940	7	30	37	9.9	1.3	----		2.5
DWORSHAK	ID	463000	488	6315.0	6920.0	282.0	192.0	62.0	3468000	0.790	5	21	30	4.4	4.6	47.00		0.5
ISLAND PARK	ID	442400	1920	----	3153.0	80.0	22.0	5.0	127269	0.280	6	---	150	5.7	4.5	----	N	30.
LUCKY PEAK	ID	433200	933	6547.0	1153.0	66.0	64.0	24.4	228060	0.100	4	---	70	2.5	5.0	----	N	2.9
MACKAY	ID	435700	1847	1892.0	542.0	12.0	---	10.0	43936	0.490	9	3	219	1.3	4.5	----	N	21.
PALISADES	ID	431700	1713	13478.0	6515.0	107.0	32.0	26.5	1400000	0.290	12	39	220	1.5	3.5	----	N	8.3
PAYETTE	ID	445730	1524	373.0	2160.0	38.0	95.0	35.0	612840	2.320	5	6	20	1.0	9.0	----	N	0.6
PEND OREILLE	ID	480730	629	59265.0	38348.0	310.0	351.0	164.0	50987714	2.740	15	11	180	2.0	6.5	4.00	Y	1.1
PRIEST LAKE	ID	483100	652	1480.0	9454.0	109.0	112.0	38.0	2912224	3.120	4	4	50	1.5	8.2	1.00	Y	1.3
REDFISH LAKE	ID	440700	1996	103.0	608.0	15.0	89.0	46.0	226718	---	6	6	---	----	14.0	----	N	---
SPIRIT LAKE	ID	475630	686	125.0	598.0	21.0	27.0	10.9	52853	---	8	18	240	5.3	3.9	----		22.
STANLEY	ID	431400	1984	38.0	74.0	4.0	27.0	15.0	9160	---	7	---	---	----	11.0	----		---
UPPER PRIEST	ID	484600	744	1481.0	567.0	14.0	30.0	12.0	55155	---	4	6	100	2.9	6.0	----	Y	8.3
** MT																		
FLATHEAD LAKE	MT	-----	882	18400.0	51039.0	200.0	113.0	32.5	13448210	2.200	10	5.4	---	----	7.0	3.00	Y	---
LIBBY/KOOCANUSA	MT	490000	741	23491	18160	360	113	38.4	4711013	0.670	20	18	230	2.5	4.0	33	N	5.9
MARY RONAN	MT	475500	1128	83.6	602.0	11.0	14.3	9.0	45431	0.057	8	---	123	----	4.5	1.00	N	13.
** OR																		
ODELL	OR	-----	1459	----	1454.0	---	86.0	41.0	4889802	---	12	---	32	2.9	8.1	----	N	0.7
WALLOWA LAKE	OR	452006	1336	126.0	610.0	13.2	91	49	243500	2.500	14	.05	93	1.9	11.0	----	Y	1.3
** UT																		
FLAMING GORGE	UT	405400	1841	38971.3	13778.0	---	153.0	33.9	3783246	2.300	--	30	710	4.2	3.6	----		21.
PORCUPINE	UT	-----	1615	91.0	80.0	---	42.4	20.1	13190	---	--	---	---	----	2.1	----	N	---
** WA																		
ALDER LAKE	WA	464809	368	740.7	1254.6	45.1	88.4	22.9	230000	---	--	29	40	----	3.0	----	N	1.7
AMERICAN LAKE	WA	470630	72	65.8	445.2	19.3	27.4	16.2	60000	---	7	90	95	----	5.4	----	N	5.9

REGIONAL DATA BASE
LAKE CHARACTERISTICS

BODY OF WATER	ST	LAT	ELEV (M)	DRAIN AREA (KM2)	SURFACE AREA (HA)	SHORE LENGTH (KM)	MAX DEPTH (M)	MEAN DEPTH (M)	VOLUME (ACFT)	FLUSH RATE (YR)	THERMO-CLINE (M)	TOTAL PHOS. (UG/L)	COND	CHLOR "A" (UG/L)	SECCHI DEPTH (M)	DRAW DOWN (M)	MYS Y/N	MEI
ANGLE LAKE	WA	472530	111	2.1	40.5	3.5	15.8	7.6	2600	---	--	46	72	----	4.9	----	N	9.4
BAKER LAKE	WA	483858	221	557.0	2017.4	---	---	43.7	220600	---	--	---	---	----	-----	15.20	N	---
BANKS LAKE	WA	473703	479	----	11008.0	131.5	52.0	13.5	1300000	0.480	24	49	112	2.6	3.0	4.60	N	8.3
BILLY CLAPP L.	WA	472654	407	----	405.0	22.5	33.5	19.8	65000	0.020	--	33	165	----	2.5	----	N	8.3
BONAPARTE LAKE	WA	484735	1084	18.1	66.8	9.1	33.6	10.1	5500	---	--	50	225	----	3.7	----	N	22.
BUMPING LAKE	WA	465200	1045	----	526.0	---	36.8	11.2	47687	0.450	9	73	40	0.8	4.7	6.10	N	3.6
CASCADE LAKE	WA	483850	105	8.9	68.8	5.1	21.3	8.2	4600	---	--	6	180	----	6.1	----	N	21.
CAVANAH	WA	481950	307	19.1	323.8	12.2	24.4	13.4	36000	---	8	---	30	----	4.6	----	N	2.2
CHAIN LAKE	WA	480305	588	195.3	35.6	8.3	39.7	10.1	2900	---	--	48	523	----	4.9	----	N	51.
CHAPMAN LAKE	WA	472123	657	125.6	60.7	9.0	48.8	20.1	9900	---	--	32	240	----	1.0	----	N	11.
CHELAN LAKE	WA	475004	339	2393.2	13354.9	175.7	453.0	144.0	15807392	11.000	35	3	50	0.7	13.0	7.00	Y	0.3
CLE ELUM LAKE	WA	471443	678	525.8	1948.0	32.2	101.5	44.5	702816	1.040	12	15	57	0.8	8.8	18.30	N	1.3
CLEAR LAKE	WA	465533	237	1.1	64.7	3.4	25.9	11.6	61000	---	8	9	52	----	8.3	----	N	4.5
COOPER LAKE	WA	472516	850	72.3	52.6	5.0	15.0	6.4	2600	---	--	5	15	----	9.2	----	N	2.3
DAVIS LAKE	WA	481352	664	46.1	60.1	4.3	45.8	25.3	13000	---	--	17	85	----	3.1	----	N	3.6
DEEP LAKE-GRANT	WA	473518	376	9.0	44.0	8.8	36.6	22.3	7800	---	--	---	290	----	11.6	----	N	13.
DEEP LAKE-KING	WA	-----	235	10.2	15.0	2.1	22.6	10.1	1200	---	--	15	62	----	4.6	----	N	6.1
DEER LAKE	WA	480628	755	47.1	445.2	22.3	22.9	15.9	57000	5.940	13	30	79	----	6.3	----	N	5.0
EASTON LAKE	WA	471429	665	486.9	97.1	6.5	12.2	5.2	4000	---	--	5	40	----	4.9	----	N	7.7
KACHEES LAKE	WA	471553	687	165.5	1516.0	62.2	131.3	66.4	818616	3.890	14	11	47	0.5	8.5	7.30	N	0.7
KEECHELUS LAKE	WA	471920	768	141.7	1039.0	24.0	98.7	37.4	313973	1.400	8	33	44	2.0	6.8	16.40	N	1.2
LOON LAKE	WA	480320	726	36.7	457.3	20.5	30.5	14.0	51500	---	10	30	148	----	6.1	----	N	10.
LOST LAKE	WA	471953	924	7.7	68.8	5.0	51.9	21.7	12000	---	--	3	20	----	10.4	----	N	0.9
MERIDIAN LAKE	WA	472130	113	2.6	60.7	4.0	27.4	12.4	648	---	--	70	78	3.2	4.1	----	N	6.3
MERWIN LAKE	WA	455726	73	1890.7	1618.8	51.5	57.9	30.5	404552	0.120	9	---	---	----	5.0	3.00	N	---
MOUNTAIN LAKE	WA	483901	278	5.9	72.8	6.8	42.7	14.9	8800	---	--	8	105	----	7.0	----	N	7.0
PADDEN LAKE	WA	484215	136	6.8	64.7	3.7	18.0	8.2	4300	---	10	8	78	----	6.1	0.73	N	9.5
PALMER LAKE	WA	485439	349	766.6	849.9	25.7	24.1	15.6	110000	---	--	20	250	----	2.3	----	N	16.
PIERRE LAKE	WA	485351	611	69.4	44.5	4.7	22.9	8.5	3000	---	6	94	343	9.2	4.2	----	N	40.
PIPE-LUCERNE	WA	472158	167	1.3	22.3	2.7	19.8	8.2	1500	---	5	20	49	----	3.2	----	N	6.0
RIMROCK LAKE	WA	463800	890	----	1025.0	---	53.6	23.8	198000	0.530	--	43	68	1.5	1.5	17.40	N	2.8
ROESIGER SO.ARM	WA	475819	174	9.2	56.7	4.8	21.3	6.7	3000	---	--	24	---	2.9	4.3	0.40	N	---
ROESIGER-NO.ARM	WA	475917	174	5.0	80.9	4.6	33.5	14.6	9600	---	--	28	26	2.3	5.6	0.40	N	---
SAMMAMISH LAKE	WA	473500	8	253.0	1982.0	39.8	31.0	17.7	283722	0.600	10	21	---	3.4	4.0	1.00	N	---
SAWYER LAKE	WA	472003	156	33.7	121.4	11.3	17.7	7.9	7700	---	--	17	139	----	4.3	----	N	17.
SHANNON LAKE	WA	483253	133	769.2	930.8	35.4	79.2	28.3	210000	---	--	10	35	----	-----	----	N	1.2
STAR LAKE	WA	472110	97	1.5	14.2	1.8	15.2	7.6	870	---	--	---	84	----	6.7	----	N	11.
STEILACOOM LAKE	WA	471040	64	231.5	129.5	9.2	6.1	3.4	3500	---	2	30	108	----	2.1	----	N	31.
STEVENS LAKE	WA	480053	64	17.7	42.1	11.1	46.0	20.5	68442	3.380	10	20	115	15.0	4.4	1.25	N	5.6
SULLIVAN LAKE	WA	485022	789	132.6	566.6	14.3	100.7	58.0	270000	---	--	21	75	----	5.6	----	N	1.3
TOAD LAKE	WA	484723	217	1.3	13.4	1.9	9.4	6.1	660	---	--	13	88	----	2.7	----	N	14.
TROUT LAKE	WA	480702	673	122.5	38.9	2.9	54.9	13.1	4200	---	--	---	---	----	3.1	----	N	---
WASHINGTON LAKE	WA	474000	4	1564.0	8959.0	115.0	65.0	33.0	2350843	---	--	---	---	----	-----	----	N	---
WENATCHEE LAKE	WA	474831	570	707.1	10911.7	20.9	73.2	45.8	360000	---	--	5	18	----	6.1	----	N	0.3
WILDERNESS LAKE	WA	-----	143	1.7	27.9	2.9	11.6	6.4	1420	---	3	---	70	2.7	3.7	0.40	N	10.
YALE LAKE	WA	455753	149	1543.6	1537.5	41.8	76.2	33.5	402000	0.140	4	---	---	----	6.0	7.00	N	---

Appendix D. Summary report of kokanee population characteristics.
2-APPS

REGIONAL DATA BASE
KOKANEE POPULATION

BODY OF WATER	KOKANEE SOURCE	DENSITY LOW (NO/HA)	DENSITY HIGH (NO/HA)	DENSITY MEAN (NO/HA)	MEAN LN AGE 0+ (MM)	MEAN LN AGE I+ (MM)	MEAN LN AGE II+ (MM)	MEAN LN AGE III+ (MM)	MEAN LN SPAWNER (MM)	AGE AT MATURITY	ESCAPEMENT TO SPAWN (MEAN)	TIME OF SPAWNING
** BC												
KOOTENAY	NATIVE	---	---	---	55	125	174	184	205	3.0	600000	SEPT
OKANAGAN		---	---	399	57	129	209	234	---	---	-----	
UPPER ARROW	KOOTENAY	110	160	135	---	---	---	---	240	3.0	750000	SEPT
** CO												
DILLON RES.		---	---	---	---	---	---	---	300	4.0	----	
GRANBY		---	---	---	---	---	---	---	293	---	----	
GREEN MOUNTAIN		---	---	---	---	---	---	---	---	---	----	
SHADOW MOUNTAIN		---	---	---	---	---	---	---	---	---	----	
** ID												
ALTURAS		---	---	---	---	---	---	---	---	---	----	
ANDERSON RANCH	INTROD/UNKNOWN	218	848	442	57	160	225	320	---	4.0	7000	SEPT
COEUR D'ALENE	PEND OREILLE	473	1355	938	---	146	187	227	242	4.0	----	NOV/DEC
DEADWOOD		---	---	---	---	---	---	---	---	4.0	----	AUG/SEPT
DWORSHAK	WHATCOM/A.RANCH	109	109	109	50	180	240	290	316	4.0	----	
ISLAND PARK		---	---	---	---	---	---	---	---	---	----	
LUCKY PEAK		---	---	---	---	---	---	---	---	---	----	
MACKAY		---	---	---	---	---	---	---	---	---	----	
PALISADES		---	---	---	---	---	---	---	---	---	----	
PAYETTE	NATIVE/PEND'OR	55	104	82	---	145	205	255	---	4.0	----	AUG/SEPT
PEND OREILLE		189	452	255	---	145	212	242	---	4.5	----	NOV/DEC
PRIEST LAKE		4	50	26	---	154	229	287	---	4.5	----	OCT/DEC
REDFISH LAKE		---	---	---	---	---	---	---	---	---	----	
SPIRIT LAKE		496	1465	983	45	166	211	248	---	---	----	NOV/DEC
STANLEY		---	---	---	---	---	---	---	---	---	----	
UPPER PRIEST		28	79	79	---	133	210	280	---	---	----	OCT/DEC
** MT												
FLATHEAD LAKE	INTRO./UNKNOWN	16	25	19	99	231	299	321	356	4.0	----	OCT/DEC
LIBBY/KOOCANUSA	INTRODUCED	---	---	214	---	164	295	---		2.0	----	SEPT/OCT
MARY RONAN	FLATHEAD	---	---	---	---	---	---	---		3.0	----	OCT/NOV
** OR												
ODELL	KOOTENAY/FLATHD	36	124	88	47	151	220	320	327	4.0	----	OCT/NOV
WALLOWA LAKE	NATIVE/STOCKED	---	---	---	---	---	---	---		---	----	
** UT												
FLAMING GORGE		---	---	---	---	---	---	---	---	---	----	
PORCUPINE	INTRO.	---	---	---	---	124	257	364	---	3.0	----	SEPT
** WA												
ALDER LAKE		---	---	---	---	---	---	---	---	---	----	
AMERICAN LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	

REGIONAL DATA BASE
KOKANEE POPULATION

BODY OF WATER	KOKANEE SOURCE	DENSITY LOW (NO/HA)	DENSITY HIGH (NO/HA)	DENSITY MEAN (NO/HA)	MEAN LN AGE 0+ (MM)	MEAN LN AGE I+ (MM)	MEAN LN AGE II+ (MM)	MEAN LN AGE III+ (MM)	MEAN LN SPAWNER (MM)	AGE AT MATURITY	ESCAPEMENT TO SPAWN (MEAN)	TIME OF SPAWNING
ANGLE LAKE	INTRO./UNKNOWN	---	---	---	---	---	---	---	---	---	----	
BAKER LAKE	NATIVE	---	---	---	---	---	---	---	---	---	----	
BANKS LAKE	NATIVE/WHATCOM	---	---	---	---	---	302	400	---	4.0	----	OCT/NOV
BILLY CLAPP L.	NATIVE/WHATCOM	---	---	---	---	135	226	273	---	4.0	----	OCT/NOV
BONAPARTE LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
BUMPING LAKE	NATIVE/WHATCOM	---	---	---	---	---	133	144	---	---	----	
CASCADE LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
CAVANAH	INTRO./UNKNOWN	---	---	---	---	---	---	---	---	---	----	
CHAIN LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
CHAPMAN LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
CHELAN LAKE	WHATCOM/KOOTENA	---	---	---	---	---	292	320	---	4.5	----	SEPT/OCT
CLE ELUM LAKE	NATIVE/WHATCOM	---	---	---	---	---	---	---	---	---	----	
CLEAR LAKE		---	---	---	113	214	310	---	---	3.0	----	
COOPER LAKE	NATIVE/WHATCOM	---	---	---	---	---	---	---	---	---	----	
DAVIS LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
DEEP LAKE-GRANT	WHATCOM	---	---	---	---	---	---	---	---	---	----	
DEEP LAKE-KING	INTRO./UNKNOWN	---	---	---	---	---	---	---	---	---	----	
DEER LAKE	WHATCOM	---	---	---	---	---	302	400	---	---	----	
EASTON LAKE		---	---	---	---	---	---	---	---	---	----	
KACHEES LAKE	NATIVE/WHATCOM	---	---	---	---	---	---	---	---	---	----	
KEECHELUS LAKE	NATIVE/WHATCOM	---	---	---	---	---	---	---	---	---	----	
LOON LAKE	WHATCOM	---	---	---	---	---	218	228	---	---	----	
LOST LAKE	WHATCOM	---	---	---	---	---	133	171	---	---	----	
MERIDIAN LAKE	INTRO./UNKNOWN	---	---	---	---	---	---	---	---	---	----	
MERWIN LAKE	INTRO./UNKNOWN	---	---	---	---	---	380	---	---	3.0	----	SEPT/OCT
MOUNTAIN LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
PADDEN LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
PALMER LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
PIERRE LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
PIPE-LUCERNE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
RIMROCK LAKE	WHATCOM	281	310	295	---	---	171	207	---	3.0	----	SEPT
ROESIGER SO.ARM	INTRO./UNKNOWN	---	---	---	---	---	---	---	---	---	----	
ROESIGER-NO.ARM	INTRO./UNKNOWN	---	---	---	---	---	---	---	---	---	----	
SAMMAMISH LAKE		---	---	---	---	---	219	370	---	---	----	
SAWYER LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
SHANNON LAKE		---	---	---	---	---	---	---	---	---	----	
STAR LAKE	INTRO./UNKNOWN	---	---	---	---	---	---	---	---	---	----	
STEILACOOM LAKE	INTRO./UNKNOWN	---	---	---	---	---	---	---	---	---	----	
STEVENS LAKE	WHATCOM	---	---	---	---	---	230	287	258	2.5	----	NOV/JAN
SULLIVAN LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
TOAD LAKE	INTRO/UNKNOWN	---	---	---	---	---	---	---	---	---	----	
TROUT LAKE	WHATCOM	---	---	---	---	---	---	---	---	---	----	
WASHINGTON LAKE		---	---	---	---	---	---	---	---	---	----	
WENATCHEE LAKE	NATIVE/WHATCOM	---	---	---	---	---	---	---	---	---	----	
WILDERNESS LAKE		---	---	---	---	---	---	---	---	---	----	
YALE LAKE	CULTAS LAKE ?	---	---	---	---	---	320	---	---	2.0	----	SEPT/OCT

Appendix E. Summary report of kokanee fisheries.

2-APPS

REGIONAL DATA BASE
FISHERY

BODY OF WATER	TOTAL EFFORT (HRS)	KOKANEE EFFORT (%)	KOKANEE HARVEST (LOW)	KOKANEE HARVEST (HIGH)	KOKANEE HARVEST (MEAN)	MEAN SIZE KOKANEE (GRAMS)	KOKANEE YIELD (KG/HA)	PREDATOR HARVEST (MEAN)	MEAN SIZE PREDATOR (GRAMS)	PREDATOR YIELD (KG/HA)
** BC										
KOOTENAY	130000	25	25000	100000	50000	90	0.120	----	----	----
OKANAGAN	200000	50	----	----	156000	174	0.773	----	----	----
UPPER ARROW	9200	34	5000	21000	13600	129	1.980	----	----	----
** CO										
DILLON RES.	210000	--	----	----	67575	179	9.324	----	----	----
GRANBY	135631	--	----	----	58000	285	5.630	1126	830	0.320
GREEN MOUNTAIN	125000	--	----	----	14200	401	6.701	522	320	0.200
SHADOW MOUNTAIN	----	--	----	----	----	---	----	----	----	----
** ID										
ALTURAS	11342	--	----	----	107	71	0.023	----	----	----
ANDERSON RANCH	86553	86	----	----	33600	247	4.327	13900	----	----
COEUR D'ALENE	250036	93	238903	578034	521517	215	3.182	350	8200	0.230
DEADWOOD	----	--	----	----	----	---	----	----	----	----
DWORSHAK	108696	61	32000	207000	206976	143	4.281	----	----	----
ISLAND PARK	97631	--	----	----	158	326	0.016	----	----	----
LUCKY PEAK	----	--	----	----	----	---	----	----	----	----
MACKAY	----	--	----	----	----	---	----	----	----	----
PALISADES	----	--	----	----	----	---	----	----	----	----
PAYETTE	18855	13	----	----	1276	206	0.122	----	----	----
PEND OREILLE	355514	70	----	----	838460	120	2.632	----	----	----
PRIEST LAKE	68186	--	----	----	84131	140	1.246	----	----	----
REDFISH LAKE	----	--	----	----	1400	112	0.259	----	----	----
SPIRIT LAKE	70573	78	----	----	59480	128	12.741	----	----	----
STANLEY	11326	--	----	----	150	55	0.112	----	----	----
UPPER PRIEST	----	--	----	----	----	---	----	----	----	----
** MT										
FLATHEAD LAKE	600000	83	----	----	495910	270	2.627	12399	----	----
LIBBY/KOOCANUSA	394354	98	----	----	414480	354	8.650	----	----	----
MARY RONAN	35963	90	----	----	129625	165	35.442	----	----	----
** OR										
ODELL	157000	73	11600	89300	64000	230	10.500	----	----	----
WALLOWA LAKE	23033	--	----	----	25982	106	4.520	----	----	----
** UT										
FLAMING GORGE	328000	--	737	38816	30294	623	1.110	10536	2388	1.410
PORCUPINE	----	--	----	----	1580	299	6.000	----	----	----
** WA										
ALDER LAKE	----	--	----	----	----	---	----	----	----	----
AMERICAN LAKE	140500	--	14970	64299	32914	---	----	16394	----	----
ANGLE LAKE	----	--	----	----	----	---	----	----	----	----

REGIONAL DATA BASE
FISHERY

BODY OF WATER	TOTAL EFFORT (HRS)	KOKANEE EFFORT (%)	KOKANEE HARVEST (LOW)	KOKANEE HARVEST (HIGH)	KOKANEE HARVEST (MEAN)	MEAN SIZE KOKANEE (GRAMS)	KOKANEE YIELD (KG/HA)	PREDATOR HARVEST (MEAN)	MEAN SIZE PREDATOR (GRAMS)	PREDATOR YIELD (KG/HA)
BAKER LAKE	----	--	----	----	----	---	----	----	----	----
BANKS LAKE	186363	86	17630	75035	60740	453	2.500	4827	----	----
BILLY CLAPP L.	11509	90	----	----	6126	260	2.222	160	----	----
BONAPARTE LAKE	----	--	----	----	----	---	----	----	----	----
BUMPING LAKE	----	80	----	----	----	---	----	----	----	----
CASCADE LAKE	----	--	----	----	----	---	----	----	----	----
CAVANAH	----	--	----	----	----	---	----	----	----	----
CHAIN LAKE	----	--	----	----	----	---	----	----	----	----
CHAPMAN LAKE	----	--	----	----	----	---	----	----	----	----
CHELAN LAKE	----	--	----	----	6000	199	0.090	65	----	----
CLE ELUM LAKE	----	--	----	----	----	---	----	----	----	----
CLEAR LAKE	----	--	----	----	----	---	----	----	----	----
COOPER LAKE	----	--	----	----	----	---	----	----	----	----
DAVIS LAKE	----	--	----	----	----	---	----	----	----	----
DEEP LAKE-GRANT	----	--	----	----	----	---	----	----	----	----
DEEP LAKE-KING	----	--	----	----	----	---	----	----	----	----
DEER LAKE	----	--	----	----	584	680	0.893	1428	----	----
EASTON LAKE	----	--	----	----	----	---	----	----	----	----
KACHEES LAKE	----	--	----	----	----	---	----	----	----	----
KEECHELUS LAKE	----	--	----	----	----	---	----	----	----	----
LOON LAKE	----	--	----	----	584	556	0.711	118	----	----
LOST LAKE	----	--	----	----	----	---	----	----	----	----
MERIDIAN LAKE	----	--	----	----	----	---	----	----	----	----
MERWIN LAKE	29222	51	----	----	4693	237	0.687	----	----	----
MOUNTAIN LAKE	----	--	----	----	----	---	----	----	----	----
PADDEN LAKE	----	--	----	----	----	---	----	----	----	----
PALMER LAKE	----	--	----	----	----	---	----	----	----	----
PIERRE LAKE	----	--	----	----	----	---	----	----	----	----
PIPE-LUCERNE	----	--	----	----	----	---	----	----	----	----
RIMROCK LAKE	----	95	----	----	----	---	----	----	----	----
ROESIGER SO.ARM	----	--	----	----	----	---	----	----	----	----
ROESIGER-NO.ARM	----	--	----	----	----	---	----	----	----	----
SAMMAMISH LAKE	33400	--	----	----	359	442	0.080	----	----	----
SAWYER LAKE	----	--	----	----	----	---	----	----	----	----
SHANNON LAKE	----	--	----	----	----	---	----	----	----	----
STAR LAKE	----	--	----	----	----	---	----	----	----	----
STEILACOOM LAKE	----	--	----	----	----	---	----	----	----	----
STEVENS LAKE	----	--	----	----	----	---	----	----	----	----
SULLIVAN LAKE	----	--	----	----	----	---	----	----	----	----
TOAD LAKE	----	--	----	----	----	---	----	----	----	----
TROUT LAKE	----	--	----	----	----	---	----	----	----	----
WASHINGTON LAKE	----	--	----	----	----	---	----	----	----	----
WENATCHEE LAKE	----	--	----	----	----	---	----	----	----	----
WILDERNESS LAKE	----	--	----	----	----	---	----	----	----	----
YALE LAKE	23819	72	3398	19346	10919	250	1.779	33	----	----

Appendix F. Sources of information.

REGIONAL DATA BASE
Sources of Information by Water

Body *of* Water	Sources of Information
tt BC	
KOOTENAY	51
OKANAGAN	10,51
UPPER ARROW	51
tt CO	
DILLON RES.	64
GRANBY	64
GREEN MOUNTAIN	64
SHADOW MOUNTAIN	64
tt ID	
ALTURAS	49
ANDERSON RANCH	29,49
COEUR D'ALENE	13,29,39,40,41,49,60,61
DEADWOOD	29,49
DWORSHAK	1,29,31,46,47,48
ISLAND PARK	29,49
LUCKY PEAK	29,49
MACKAY	29,49
PALISADES	29,49
PAYETTE	29,49,63
PEND OREILLE	2,3,5,6,7,22,29,32,39,40,41,49,56,57,58
PRIEST LAKE	1,4,5,13,14,15,29,39,40,41,48,49
REDFISH LAKE	49
SPIRIT LAKE	13,14,49,58
STANLEY	49
UPPER PRIEST	13,14,15,45,52
It MT	
FLATHEAD LAKE	26,27,28
LIBBY/KOOCANUSA	12,65,71
MARY RONAN	18,19
tt OR	
ODELL	11,42,43,44
WALLOWA LAKE	36
St UT	
FLAMING GORGE	9
PORCUPINE	34
tt WA	
ALDER LAKE	16
AMERICAN LAKE	65
ANGLE LAKE	16
BAKER LAKE	35

Body *of* Water	Sources of Information
BANKS LAKE	67,68,69,70
BILLY CLAPP L.	70
BONAPARTE LAKE	72
BUMPING LAKE	50
CASCADE LAKE	35
CAVANAH	37
CHAIN LAKE	30
CHAPMAN LAKE	54
CHELAN LAKE	9,53
CLE ELUM LAKE	50
CLEAR LAKE	16
COOPER LAKE	9
DAVIS LAKE	30
DEEP LAKE-GRANT	33
DEEP LAKE-KING	16
DEER LAKE	62
EASTON LAKE	9
KACHEES LAKE	49
KEECHELUS LAKE	9,50
LOON LAKE	62
LOST LAKE	9
MERIDIAN LAKE	16
MERWIN LAKE	20,24,45
MOUNTAIN LAKE	35
PADDEN LAKE	35
PALMER LAKE	72
PIERRE LAKE	30
PIPE-LUCERNE	16
RIMROCK LAKE	17
ROESIGER SO.ARM	37
ROESIGER-NO.ARM	37
SAMMAMISH LAKE	55
SAWYER LAKE	16
SHANNON LAKE	35
STAR LAKE	16
STEILACOOM LAKE	16
STEVENS LAKE	55
SULLIVAN LAKE	30
TOAD LAKE	35
TROUT LAKE	30
WASHINGTON LAKE	55
WENATCHEE LAKE	9
WILDERNESS LAKE	16
YALE LAKE	24,45

Regional Data Base
Sources of Information

REF HO.	SOURCE	YEAR	PUBLICATION	AGENCY
1	Bail, K., and S. Pettit	1971	Evaluation of the limnological characteristics and fisheries of Dworshak Reservoir. Job Performance Report, Project OSS-29-9, Job IV	Idaho Department of Fish and Game, Boise
2	Bowler, B.	1975	Lake Pend Oreille kokanee life history studies, Job Performance Report, Project F-53-R-11, Job IV-E	Idaho Department of Fish and Game, Boise
3	Bowler, B.	1976	Lake Pend Oreille kokanee life history studios, Job Performance Report, Project No. F-53-R-11, Job IY-E	Idaho Department of Fish and Game, Boise
4	Bowler, B.	1979	Kokanee life history studios in Priest Lake. Lake and Reservoir Investigations, Job Performance Report, Project Ho. F-73-R-2, Study V, Job III	Idaho Department of Fish and Game, Boise
5	Bowler, B.	1980	Kokanee life history studies in Pond Oreille Lake. Lake and Reservoir Investigations, Job Performance Report, Project No. F-73-R-2	Idaho Department of Fish and Game, Boise
6	Bowles, E.C., V.L. Ellis, D. Hatch, and D. Irving	1987	Kokanee stock status and contribution of Cabinet Gorge Hatchery, Lake Pend Oreille, Idaho. Annual Report to BPA, project 85-339	Idaho Department of Fish and Game, Boise
7	Bowles, E.C., V.L. Ellis, and D. Hatch	1988	Kokanee stock status and contribution of Cabinet Gorge Hatchery, Lake Pend Oreille, Idaho. Annual Progress Report FY 1987	Idaho Department of Fish and Game, Boise
8	Brayton, S. and R. Schneidervin	1983	(1983-1989) Flaming Gorge Reservoir Fisheries Investigations. Annual Performance Report	Utah Division of Wildlife Resources, Salt Lake City
9	Brown, Larry			(509) 663-9711
10	Bull, C.J.	1987	Okanagan lake plan	Okanagan sub-region technical report
11	Campbell, H.J.	1965	A preliminary investigation of the kokanee in Odell Lake, Oregon. Federal Aid Project No. F- 7 1-R.-1	Oregon Game Commisssion
12	Chisholm, I., M.E. Hensler, B. Hansen, and D. Skaar	1989	Quantification of Libby reservoir levels needed to maintain or enhance reservoir fisheries, methods and data summary 1983-1987	Montana Department of Fish, Wildlife and Parks, Kalispell, Montana

Regional Data Base
Sources of Information

REF NO.	SOURCE		PUBLICATION	AGENCY
13	Cochnauer, T.	1983	Kokanee Stock Status in Pend Oreille, Priest, and Coeur d'Alene Lakes. Job Performance Report, Project F-73-R-5	Idaho Department of Fish and Game, Boise
11	Cochnauer. T.	1981	Enhancement of kokanee in Priest and Pend Or-eille Lakes, Job Performance Report, Project No. F-7:3-R-6, Study 4'I, Job IU	Idaho Department of Fish and Game, Boise
15	Cochnauer. T.	1982	Kokanee stock monitoring in Coeur d'Alene and Priest Lakes, Lake and Reservoir Investigations, Job Performance Report, Project Mo. F-73-R-9	Idaho Department of Fish and Game, Boise
16	Cropp.Tom			Washington Department of Fish and Wildlife (206) 898-0590
17	Cummins, J.	1981	Rimrock resident fishery	(509) 753-5713
18	Domrose, R.	1987	Lake Mary Ronan Monitoring Report 1965-1986.	Montana Department of Fish, Wildlife and Parks, Kalispell, Montana
19	Domrose. R.		Summary of Lake Mary Ronan summer creel census, 1986 Lake Mary Ronan winter creel 1969, 1985, 1987, 1988, 1989, 1990	Montana Department of Fish, Wildlife and Parks, Kalispell, Montana
20	Eddy, B., and P. Meyers.	1985	Evaluation of the contribution of coho to the 1981 Merwin Reservoir sport fishery.	Pacific Power and Light Company, Portland, Oregon. (503) 969-9221
21	Ellis, V.L., B. Rieman, and T. Cochnauer	1982	Kokanee lake systems inventory - Spirit Lake. Lake and Reservoir Investigations, Job Performance Report, Project No. F-73-R-9	Idaho Department of Fish and Game, Boise
22	Ellis, V.L., and B. Bowler	1980	Pond Oreille Lake creel census. Lake and Reservoir Investigations, Job Performance Report, Project No. F-73--R-2, Job I	Idaho Department of Fish and Game, Boise
23	Ellis, V.L>, and B. Bowler	1979	Pend Oreille Lake creel census. Lake and Reservoir Investigations, Job Performance Report, Project No. F-72-R-1	Idaho Department of Fish and Game, Boise
21	Graves, S.K.	1981	Merwin, Yale, and Swift Reservoir study 1970-1979. Progress Report, Reservoir Fisheries	

Regional Data Base
Sources if Information

REF HD.	SOURCE --		PUBLICATION	AGENCY
25	Hanson, Barry		Summary of BRA publications. Quantification of Libby Reservoir levels needed to maintain or enhance reservoir fisheries, 1983, 1981, . 1 9 8 5 , 1989	Montana Department of Fish, Wildlife and Parks, Libby, Montana
26	Hanzel, D.R.	1981	Lake fisheries inventory - annual trends in recruitment and migration of kokanee populations and major factors affecting trends. Job Completion Report	Montana Department of Fish, Wildlife, and Parks, Kalispell
27	Hanzel, D.H.	198?	Measure annual trends in the recruitment and migration of kokanee populations and identify major factors affecting trends. Job Completion Report	Montana Department of Fish, Wildlife, and Parks, Kalispell
28	Hanzel, O.R., J. Fraley, and W. Beattie	1988	Survey and Inventory of coldwater and warmwater ecosystems. Statewide Fisheries Investigations, Job Progress Report F-33-R-21	Montana Department of Fish Wildlife, and Parks, Kalispell
29	Harnberg, W.R., M.L. Jones, I. O'de11, and S.C. Cordes.	1988	Water Resource Data, Idaho, Water Year 1988	U.S.G.S. Water-Data Report ID-88-1.
30	Hista, John			(509) 156-1085
31	Horton, W.D.	1981	Dworshak Reservoir fisheries investigations. Report to U.S.RrMy Corps of Engineers, Contract No. DRC:W68-79-C-0039	Idaho Department of Fish and Game, Boise
32	Irizarry, R.R., and V.L. Ellis	1975	Lake Pend Oreille creel census. lake and Reservoir Investigations, Job Performance Report, Project No. F--53-R--10, Job IU-a	Idaho Department of Fish and Game, Boise
33	Jackson, Steve			(206) 586-7075
34	Janssen, J.F.	1983	Investigation of selected aspects of kokanee (oncorhynchys nerka) ecology in Porcupine Reservoir, Utah, with management implications. Masters Thesis	Utah State University, Logan
35	Johnston, Jim			Washington Department of Wildlife (206) 671-2036
36	Knox, Bill			Oregon Department of Fish and Wildlife, Enterprise, Oregon (503) 126-3279

Regional Data Base
Sources of Information

REF NO.	SOURCE	YEAR	PUBLICATION	AGENCY
37	Kraemer, Curt			(206)775-1311
38	LaBolle, L.	1986	Enhancement of kokanee of Priest and Pend Oreille lakes, Lake and Reservoir Investigations, Job Performance Report, Project No. F-73-R-12	Idaho Department of Fish and Game,Boise
39	LaBolle, L.D.	1988	Region 1 lowland lakes investigations. Regional Fishery Management Investigations, Job Performance Report, Project No. F-71-R-12, Job I-b	Idaho Department of Fish and Game, Boise
40	LaBolle, L.D., and N. J. Horner	1987	Region 1 lowland lakes investigations, Regional Fishery Management Investigations, Job Performance Report, Project No. F-71-R-11, Job I-b	Idaho Department of Fish and Game, Boise
41	LaBolle, L.D., and N.J. Horner	1986	Region 1 lowland lakes investigations. Regional Fishery Management Investigations, Job Performance Report, Project No. F-71-R-12, Job I-b	Idaho Department of Fish and Game, Boise
42	Lewis, S.L.	1974	Population dynamics of kokanee salmon in Odell Lake. Progress Report, Federal Aid Project No. F-71-R-6 No. 6 and 10.	Oregon State Game Commission, Portland
43	Lewis, S.L.	1971	Life history and ecology of kokanee in Odell Lake. Progress Report, Federal Aid Project No. F-71-R-6, Jobs no. 6 and 10	Oregon State Game Commission, Portland
44	Lindsay, R.B., and S.L. Lewis	1978	Lake and reservoir investigations (kokanee ecology). Federal Aid Project No. F-71-R, Jobs No. 10 and 11	Oregon Wildlife Commission, Portland
45	Lucas, Bob			(206) 423-9341
46	Maiole, M.A.	1988	Dworshak Dam impacts assessment and fishery investigation, BPA Project No. 87-99, Contract No. DE-AI79-87BP35167	U.S. Department of Energy, Portland, Oregon
47	Mauser G., D. Cannamela, and R. Downing	1989	Dworshak Dam impact assessment and fishery investigations. BPA Contract No. DE-AI79-87BP35167	Idaho Department of Fish and Game, Boise
48	Mauser, G.R., and V. Ellis	1985	Enhancement of trout in large north Idaho lakes. Lake and Reservoir investigations, Project No. F-73-R-6, Job II	Idaho Department of Fish and Game, Boise
49	Milligan,J.H., R.A. Lyman, C.M. Falter, E.E. Krumpe, and J.E. Carlson	1983	Classification of Idaho's freshwater lakes.	Idaho Water and Energy Resources Research Institute, University of Idaho

Regional Data Base
Sources of Information

REF NO.	SOURCE	YEAR	PUBLICATION	AGENCY
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51	Parkinson, E.			
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